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# THE GEOLOGY OF BURMA

BY

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TO

MY WIFE

SHRIMATI VIDYA VATI CHHIBBER,

in appreciation of her affectionate spirit of sacrifice and willing determination to help me in my small endeavours

# PREFACE

The interest of the Geology of Burma and the importance of its mineral resources need scarcely be emphasized. In the domain of historical geology the country furnishes an almost complete record of Palaeozoic and Mesozoic rocks in the Federated Shan States and of the Tertiary rocks in the Central Belt. The records, especially of the Palaeozoic periods, offering as they do an interesting comparison with their Himalayan equivalents are so replete with interest that the Federated Shan States really constitute an easily accessible field-museum of Geology. But the information about the physical geography, geology and mineral resources of Burma is widely scattered in scientific publications and hence it remains comparatively little known.

As a lecturer on Geology and Geography to the intermediate and degree students of the University of Rangoon, I felt very keenly the absence of a handy manual on the subject, and to supply that want has been my aim in writing these volumes. It is hoped, therefore, that they will fulfil the requirements of University students and, at the same time, afford a useful guide to all who are interested in the subject.

It was originally my intention to cover in one volume both the Geology and the Mineral Resources of Burma; but when the work was well advanced it was deemed advisable to publish two complementary volumes, thus allowing both aspects to be dealt with more exhaustively than would otherwise have been possible.

Some portions of the books have been written entirely from personal observation. It was always my endeavour to make myself familiar with the rock-formations of Burma and the occurrence of its mineral resources. With this end in view I travelled extensively all over the country from Mergui to Myitkyina and from the Shan States to Akyab during the years 1924 to 1928. To investigate some of the areas I received research grants from the University of Rangoon, to which body I should

like to take this opportunity of tendering my sincere thanks. I must have also benefited in my geological knowledge while working on behalf of the Geological Survey of India from 1928 onwards.

I accept entire responsibility for writing twenty-three Chapters, viz. Chapters I-X, XVII-XX, XXIV, and XXVII-XXXIV. The first draft of the Chapters XI-XVI and XXI-XXV was drawn up conjointly with Mr. R. Ramamirtham, and I have the greatest pleasure in expressing my thanks for his collaboration. These chapters were, however, subsequently extensively revised and in all cases sections have been added, so that the responsibility for the final form of these chapters as now published is also mine.

Dr. L. Dudley Stamp, formerly Professor of Geology and Geography, University College, University of Rangoon, has very kindly written the Foreword. He also read some of the proofs and freely gave his advice, which was often sought on matters connected with the book. In expressing my gratitude to him I wish to associate Mrs. E. C. Stamp's name with it.

I wish to tender my most sincere thanks to Mr. D. J. Sloss, C.B.E., M.A., I.E.S., Principal of the University College, Rangoon. His general advice in matters connected with research and my department from 1926–1928 was always stimulating and most helpful. To Dr. J. Coggin Brown I have already expressed, in a previous publication, my indebtedness for all the warm sympathy and encouragement I received during his tenure as Superintendent-in-charge of the Burma Party of the Geological Survey of India. He has very kindly corrected the proofs and some portion of the manuscript.

To my Director, Dr. L. L. Fermor, and his predecessor, Sir Edwin H. Pascoe, I am very greatly indebted for permission to publish this book and to reproduce some of the illustrations, though it had been mainly written before my joining the Department. Dr. Fermor I wish to thank for offering constructive criticism on some of the chapters on Igneous Activity. I also wish to thank Dr. A. M. Heron for correcting the age of the Tenasserim volcanic rocks. I also offer my best thanks to the Cambridge University Press, the American Journal of Science, the Mining and Geological Institute of India for kindly according

me the permission to reproduce the illustrations, the source of which in each case is acknowledged in the List.

Professor P. G. H. Boswell kindly corrected part of the proofs and I had also the opportunity of discussing with him the Igneous Activity of Burma in relation to its tectonics. Professor A. Brammall kindly corrected the manuscript of the chapters on Igneous Activity. In writing and rearranging these chapters his advice and suggestions were very helpful. Similarly Dr. G. W. Tyrrell of the University of Glasgow read proofs of the chapters dealing with Igneous Activity. Professor A. Morley Davies and Dr. F. R. Cowper Reed very kindly corrected the palaeontological portions of the book. To all these savants I tender my most sincere thanks.

My best thanks are also due to Mr. G. S. Sweeting for correcting some of the proofs. I had the opportunity of discussing with Dr. A. K. Wells the conclusions expressed in Chapter XXXIII. He also very kindly prepared the Index and, in addition to checking both sets of proofs, undertook the very considerable task of seeing these volumes through the press for me on my return to India at the termination of my leave. Mr. J. B. Scrivenor read and corrected proofs of the book, especially with a view to correlating the Burmese with the Malayan geology, and I am greatly obliged to him for his "Note on the Correlation of the Burmese Geology with that of Malaya," which appears as Appendix A to the book. Similarly I wish to express my gratefulness to Mr. P. Evans of the Burmah Oil Company, doyen of the geologists working in Assam, for so kindly contributing Appendix B to this book, outlining a correlation of the Geology of Burma with that of its neighbouring region, Assam.

I also wish to express my best thanks to the University of London for very kindly making a grant out of its Dixon Fund for the analyses of some of the rock types.

Here I would very much like to express my sincere thanks to Professor D. N. Wadia and Professor B. K. Bose, from whom I received my first lessons in Geology. I must have benefited tremendously by their inspiring teaching. Among my other old Professors of the Prince of Wales College, Jammu, Kashmir, to whom I shall remain ever grateful, I should like to mention the names of Principal S. R. Suri, Professor Manak Chand Khosla

and Dr. S. Varma. I could never forget the kindly interest taken in me by Professor Prabhu Dial Dhavan, when I happened to be his pupil in the B.Sc. chemistry classes.

I have dedicated this work to my wife, whose sympathetic understanding and spirit of sacrifice at all moments contributed not a little to make the task simpler and considerably more pleasant.

At the end of each chapter, a very comprehensive, almost complete list of references is added and statements in the text have also been supported by reference to appropriate authorities. Whenever a reference has been omitted as a footnote, it will be found at the end of the chapter.

Last but not least I thank most sincerely Messrs. Macmillan & Co. Ltd., London, for their uniform courtesy throughout the publication of this book.

H. L. CHHIBBER.

UNIVERSITY COLLEGE,
UNIVERSITY OF RANGOON, *October* 1927.
LONDON, *Jan.* 1934.

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## FOLDING MAPS



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# FOREWORD

By L. Dudley Stamp, B.A., D.Sc., M.I.P.T., F.G.S.

(Formerly Professor of Geology and Geography in the University of Rangoon)

It was in 1923 that I was entrusted by the University of Rangoon with the task of organising the new Department of Geology and Geography. The teaching organised by the Department was concerned with courses in the faculties of Arts and Science for Intermediate, Degree and Higher Degree work, whilst special instruction was arranged for students of forestry and engineering. About a year later I was joined by Dr. H. L. Chhibber, who immediately threw himself with characteristic energy into these numerous activities of the Department. He came to Rangoon from the Benares Hindu University after a brilliant career in the University of the Punjab. Within a few days he had set himself the task of mastering the study of the geology of Burma and of systematically surveying all the geographical and geological literature on the Province. He joined with me in field and laboratory work in the examination of some of the igneous rocks of the country. The need for a manual on the geology of Burma was apparent to us both, as it must be to anyone who undertakes, or attempts to undertake, an investigation of the mineral resources of the country.

Burma is still a land of the future in many respects. If the oil resources of the country have been investigated with care, there is still much to be learnt about the mineral deposits of the older rocks ; and there are still huge gaps in the geological maps of the hill regions, both to the east and to the west. A careful summary of what has up to the present been accomplished and a critical analysis by one who knows most parts of the country from personal experience is surely the essential prelude to further work. The idea of carrying out this task had crystallised itself

in Dr. Chhibber's mind not long after his arrival in the country, and he deliberately set out to qualify himself by travels, field work and laboratory study for its efficient execution. He has wisely sought the counsel and advice of the leaders of geological thought in several countries; these books are the expression of his labours.

I wish both the books and the author the success which they so richly deserve. The books will speak for themselves: that they represent a valuable combination of personal research and field work, and a minute and critical examination of existing literature will be at once apparent. Dr. Chhibber I know to be an assiduous worker, who places the progress of his studies first and foremost always, and is a scientist for science's own sake.

London School of Economics,
*June 1933.*

# CHAPTER I

## PHYSICAL FEATURES

### I. The Physical Divisions of Burma.

Burma is composed of varied structural and geological units. It is, therefore, essential to have some knowledge of its physical features before commencing the study of its stratigraphical and economic geology. The fact that the physical features of a country are mostly determined by the nature and structure of the underlying geology is admirably illustrated in the case of Burma. In fact, all its major physical features are simply the surface expression of the nature and structure of the strata lying beneath. The country thus falls naturally into the following four divisions, each of which runs from north to south, through the length of the land (see Fig. 1).

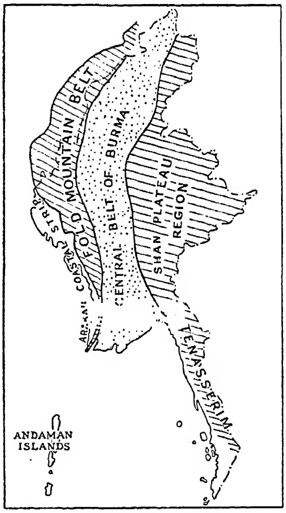

Fig. 1.—Showing the physical divisions of Burma.

1. The Shan Plateau on the east.
2. The Central Belt of Burma, covering roughly the basins of the lower Irrawaddy and its tributary, the Chindwin, and the basin of the Sittang river.
3. The fold ranges of the Arakan Yomas, the Naga and Manipur Hills, with the Lushai and Patkai Hills in the north.
4. The narrow coastal strip of Arakan.

**1. The Shan Plateau.**—This division comprises the plateau of the Shan States in the north and its southern continuation

through Karenni into the Tenasserim Yomas, which ultimately pass on into the Malay Peninsula. This region is built of Archaean, Palaeozoic and Mesozoic rocks and is distinctly marked off from the Central Tertiary region on the west, and there is often an abrupt drop of more than 2,000 feet from the edge of the plateau to the neighbouring alluvial plains of the Irrawaddy and the Sittang. There is, indeed, an almost unbroken line of jungle-covered scarp extending from north to south and forming the edge of the plateau (Plate I, Fig. 1). The strata are folded into long north-south folds, and the hills and valleys have a curious parallel arrangement as a result. The youngest rocks known to be involved in the folding of the plateau belong to the Cretaceous period. The folding is thus much earlier than that of the mountains which occur elsewhere in Burma, and so the whole system, stretching as it does from the Shan States into Malaya, is known as the "Indo-Malayan Mountain System." In those geological ages which followed the Cretaceous, the Shan Plateau formed a land mass, but hollows on its surface were occupied by lakes; a shrunken remnant of one of these is still to be seen in the Inle Lake. In the south, that is in Karenni and Tenasserim, the plateau character is lost and the country consists of long lines of hills running from north to south.

2. **The Central Belt of Burma.**—This region was the last of the great divisions of Burma to become dry land, and was occupied until the very late Tertiary period by the sea. This sea has been called the "Burmese Gulf" between the Arakan Yoma and the plateau of the Shan States. After gradual silting up, the site of the gulf was occupied by the lower course of the river Irrawaddy. The Central Belt of Burma is thus built up entirely of Tertiary sediments which were deposited in the gulf by the predecessors of the Irrawaddy and the Chindwin, by a process similar to that which is going on in the Gulf of Martaban at the present day. But the rocks have been thrown into anticlinal and synclinal folds, such as those which make up the Pegu Yoma in the middle of the belt. The principal rocks comprise sandstones, shales and clays. Where the rocks are hard they stand up as hills, and where they are soft they have been largely worn away into the lowlands and valleys. There are large areas

PLATE I.

FIG. 1.—FAULT SCARP AT PONG WO, NORTHERN SHAN STATES.

FIG. 2.—THE 'NMAI HKA, THE EASTERN HEADWATERS OF THE IRRAWADDY FLOWING THROUGH GRANITE-GNEISS COUNTRY, NEAR MILE "44" ON THE SENIKU-HTAWGAW ROAD.

On the left of the river is the "Triangle"

covered with more recent rocks and alluvium, the principal tracts of which are in the valley of the Sittang and the lower Irrawaddy, together with the deltas of these rivers. These two main areas are separated by the divide formed by the Pegu Yoma.

3. **The Western Hills Division.**—This division comprises the ranges of hills that start from Northern Assam and continue to Negrais Point in the extreme south-west of Burma. The Hill ranges in the north are the Patkoi, Lushai, Naga, Manipur and Chin Hills, all of which ultimately pass on southwards to form the Arakan Yoma. It is seen in Fig. 1 that this system is broadest in the north and narrows towards the south. The whole area consists of a series of parallel ranges, running from north to south, and between them streams flow in deep, parallel valleys, connected by transverse gaps. The streams often break through these gaps to flow back again parallel to their original course. The main range of the Arakan Yoma disappears below the sea at its lowest point, but it continues again southwards through the Andaman and Nicobar Islands to Sumatra and Java, and the whole line stretches in a double convex arc for 1,500 miles, of which 400 are under the sea; the whole constituting what is usually known as the "Burmese-Java Arc" of the Alpine-Himalayan system of folding. This area first rose from the sea towards the late Cretaceous, in the form of a long narrow island with the "Burmese Gulf" on the east and the "Assamese Gulf" on the west. This point will be discussed in greater detail later.

4. **The Coastal Strip of Arakan.**—This region lies between the Arakan Yoma on the east and the Bay of Bengal on the west. The low-lying strip of land is very narrow, and in places the hills approach close to the sea and actually form steep cliffs. Indeed it may almost be said that the Arakan Yomas themselves reach the Bay of Bengal. It is only in the neighbourhood of Akyab, that is towards the north, that there are extensive stretches of flat land. This flat land is formed by deltaic deposits of the rivers which flow from the north. The remainder of Arakan consists mainly of Tertiary rocks, of the same age as those of the Central Belt referred to above. The coast itself is

usually very rocky, and there are a number of large islands adjoining the mainland, such as Ramri and Cheduba.

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## II. The Mountains of Burma.

Burma proper, excluding Arakan, is surrounded by a mountain wall, except on the south, where the boundary is the sea. The mountains which form the edge of the Shan Plateau bound this area on the east, the Arakan Yoma and the northern continuation of the western hill ranges on the west; whilst, in the extreme north, the systems join in a great tangle of mountains which cut off northern Burma from the plain of the Brahmaputra in Assam.

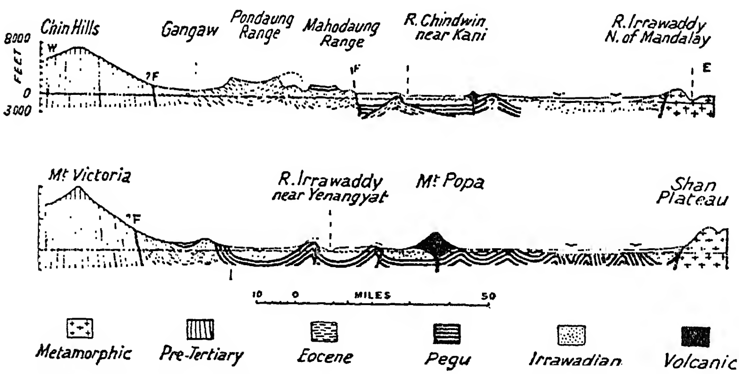


FIG. 2.—Sections from West to East across the old Tertiary gulf, showing the structure of Central Burma.

**The Arakan Yoma.**—The Arakan Yoma are the southern continuation of the mass of highlands which branch off from the east of the Himalayas. They form an arc with its convex side facing the Bay of Bengal. The system narrows southwards until the actual range disappears at Cape Negrais,

with reefs and detached rocks stretching out to sea ; the line, however, as already mentioned, is continued farther south by the rugged islands of the Andaman and Nicobar group into Sumatra and Java.

The range is still largely unknown, large areas being unsurveyed in detail. The maximum breadth in the north is about 150 miles, and the whole system is approximately 700 miles long. The highest point is believed to be the Saramati peak, rising to 12,663 feet above the sea, and long regarded as the highest point in Burma. More famous perhaps, on account of its southern position and its visibility from the Central Plain, is Mount Victoria, 10,400 feet high. Saramati deserves more than a passing reference ; it commands a range that has several peaks only a little inferior to itself. It is called by the Shans "Noimauk" or "snow mountain," which is Burmanised into "Nwèmauk." It is sometimes snow-covered in winter, but it is easily recognisable without this distinguishing feature ; for the upper part, which alone is visible from the Chindwin, is bare, and seen at sunrise from the high bank at Kaunghei, the great cone, almost as symmetrical as Fujiyama itself, rises blood-red from the dark forests of the intervening ranges. It needs no snow to enhance its beauty. It is remarkable that there is no record of any ascent of this mountain.

The structure of the Arakan Yoma chain, so far as the southern portion is concerned, is that of a great complex anticlinorium, including, according to Sir Edwin Pascoe, a number of subordinate tight folds. It is structurally closely allied to the southern and western Himalayas. The rocks forming the mountains belong to Triassic, late Cretaceous and Eocene formations—the first occurring towards the centre, the last on the flanks. From the evidence available one is forced to the conclusion that the great fold of the Arakan Yoma was initiated in the late Cretaceous times, and even as early as the Eocene constituted a barrier between the areas of deposition on the east and west respectively ; or, in other words, the Arakan Yomas were first upheaved contemporaneously with the Himalayas. During Middle Eocene times they seem to have formed a long narrow island, which was raised higher during subsequent uplifts.

Lately Tertiary sandstones from the Jade Mines area, south of the Hukawng Valley, were examined in Digboi by Mr. P. Evans of the Burma Oil Company with a view to comparing and correlating them with those of Assam. It was found that staurolite and kyanite, which are very characteristic of the Assamese Tertiaries, excepting the Barail series (Eocene-Oligocene), are absent from the Burmese Tertiaries, proving that when these rocks were being deposited the Patkai divide existed, which prevented the intermingling of the sediment-bearing currents on either side. Staurolite and kyanite are apparently derived from the Himalayan metamorphics, which have as yet not been discovered in Burma.

**The Pegu Yoma.**—The central mountains of Burma include the Pegu Yoma in the south; the Mingin Range, the Singhpho hills and other ranges in the north. The Pegu Yomas form the central chain of the country, and first appear in the Myingyan district, to continue southwards, ending in a ridge on which stands the famous Shwe Dagon Pagoda at Rangoon; though one ridge at least may be said to extend farther southwards, reappearing south of the Pegu river in the low, wooded line of hills on which stands the Syriam Pagoda. This ridge finally disappears in the rocks which, just below Kyauktan, render the navigation of the Hmaw-won dangerous to unwary boatmen. The Pegu Yomas form a divide between the valley of the Lower Irrawaddy and the valley of the Sittang. They consist of sandstones and shales dating from the Miocene and Oligocene periods, and were upheaved towards the close of the Tertiary period, thus presenting a marked contrast to the Shan Plateau on the east as well as to the Arakan Yomas on the west. This low-lying range, (not exceeding a height of 2,000 feet), therefore constitutes the youngest mountain range of Burma.

**The Northern Hill Ranges.**—North of the Irrawaddy river are the Sagaing Hills, which stretch northwards to Shwebo and farther still to the Katha District. The hills are mainly built of Tertiary rocks and, like the Pegu Yomas, do not attain very great elevations; in the Katha District, west of Wuntho, however, large areas are covered by volcanic and other igneous rocks. Another of the northern ranges, the Mingin range, lies

mainly on the borders of the Shwebo and Upper Chindwin districts. It stretches from north-north-east to south-south-west, between the valleys of the Mu and Meza rivers, both tributaries of the Irrawaddy, and attains its maximum breadth of 30 to 35 miles about lat. 24° 10′ N. It is in this range that one finds the highest volcanic mountain known in Burma—Taungthalôn, 5,600 feet above sea-level. West of the Mingin range is the Zibyun range, again composed of Tertiary rocks, but in this case not rising to a greater height than 2,000 feet above sea-level. The Zibyun range presents a steep scarp towards the east, and a gentler slope westwards. These ranges ultimately disappear in the south of the Hukawng valley.

In the extreme north of Burma near the edge of Tibet are superb chains and knots of mountains, culminating in a mighty peak, as yet unnamed, probably 19,764 feet above sea-level. This mountain occurs at the limit of the Myitkyina district. East of the Irrawaddy there is a maze of hills running through the districts of Myitkyina and Bhamo. The breadth of this complex is from 30 to 35 miles, while the peaks range from 3,000 to 11,000 feet above sea-level. Southwards these pass into the hills of the Shan Plateau.

**The Mountains of the Shan Plateau.**—On the surface of the Plateau itself there are many ranges rising to considerable elevations, but nearly always of rounded, rather than rugged outline. In the north are the hills of the Ruby Mines district; southwards are those which form the edge of the Shan Plateau, reaching a height of 4,700 feet in Mandalay, 5,000 feet in Kyaukse, and 6,000 feet in Yamethin. These continue southwards into the Karenni hills, which pass again into the Dawna range in the Thaton and Amherst districts. The general elevation of the Plateau is about 3,000 or 4,000 feet above sea-level, and it is continuous with the plateau of Yunnan. Sometimes it is noticeable that the ascent to the Plateau is built up of a series of steps; of these there is an excellent example between Zibyingyi and Thondaung stations on the Mandalay-Maymyo line. It would seem that the level stretches of ground are portions of the main Plateau which have been let down by a series of parallel faults running in a north-south direction. The surface of the Plateau is for the most part undulating, a

large part of the area constituting it being composed of limestone into which the rivers have cut deep gorges, such as the Gokteik Gorge. Few parts of the Plateau can be described as really rugged, and the mountains rise gently from the surface; the highest range, Loi Ling, is 8,771 feet above sea-level.

**The Tenasserim Yoma.**—Farther south, in the Amherst, Tavoy and Mergui districts, the southern continuation of the Shan Plateau-Karenni massif is marked by the Tenasserim Yomas. These again consist of a number of parallel ranges, with a predominantly north-south direction, separated by deep valleys. The main features of the topography are determined by granite masses, for it is these which give rise to the ranges, the previously existing sediments into which they are intruded forming the low ground. It has a maximum breadth of about 60 miles as the crow flies between the sea and the Siamese frontier in Tenasserim proper. In the Amherst and Tavoy districts the higher peaks reach heights of over 4,000 and sometimes of almost 5,000 feet above the sea. The highest point of the Tenasserim Yomas known as Myinmoletkhati, which is 6,800 feet above sea-level, is situated on the borders of Tavoy and Mergui districts. From this point the hills become lower towards the south, where they seldom rise above 2,000 feet. This type of structure is continued until Victoria Point, the southernmost limit of the province of Burma, is reached. The sedimentary rocks of Tenasserim, into which the granite has been intruded, are composed of metamorphosed sediments of the Mergui Series, with limestone of the Moulmein Series in places. Geologically, the Tenasserim Yoma is continued into Western Siam and the Malay Peninsula, which are structurally and topographically similar, and, like Lower Burma, are characterised by rich tin and tungsten ores.

The mountains of Burma are not unlike those of India proper, except that in the former the earth forces came from east or west, whilst in India proper the earth movements acted from the north or from the south, folding the rocks against the edge of the enormous massif of peninsular India. This explains the predominant north-south trend of the principal features of Burma in contrast to the east-west trend of the Himalayan mountains.

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# CHAPTER II

## THE RIVER SYSTEMS

THE predominant north-south direction of the mountain ranges of Burma is reflected also in the direction of the rivers. Not only do the smaller ones flow from north to south, and have but short east-west courses where they break through the ranges, but the largest of all the rivers, the Chindwin and the Irrawaddy, similarly follow courses which are determined by the direction of the mountain trend.

**The Irrawaddy.**—The most important river in Burma is the celebrated Irrawaddy, the Airavati of the Hindus, which means the "Elephant River." It was once thought to rise amongst the mountains of Tibet, but it is known now to be wholly a Burmese river. It rises in the hill ranges in the extreme north of the country, about lat. 29° N., and flows southwards to the head of the delta in lat. 18° N., over 770 miles as the crow flies. The river has a total drainage basin of about 160,500 square miles. The catchment basin above Bhamo has, according to modern maps, an area of only about 18,000 square miles, and is thus smaller than the Himalayan basin of the Kosi or the Sutlej. The immense discharge of water issuing from the drainage of such a small area led Gordon to believe that the old Chinese surveyors had been right, and that the San-po of Tibet flowed into the Irrawaddy. It is remarkable that the source of the Irrawaddy long remained a geographical puzzle. Gordon, in 1880, was struck by the fact that the width of the river at Bhamo is six miles, and he estimated the highest amount discharged there at 1,000,000 cubic feet per second, thus being led to identify the San-po of the Tibetan plateau with the Irrawaddy to explain the large volume of water. Wilcox later tried to disprove this contention, and

Fig. 1.—THE 'NMAI HKA, THE HEADWATERS OF THE IRRAWADDY AS SEEN FROM NEAR TANGA HKA.

various rock impediments in its course.

Fig. 2.—THE SECOND DEFILE OF THE IRRAWADDY, NEAR BHAMO.

connected the San-po with the Brahmaputra. The controversy was finally settled by the explorations of Captains Bailey and Morshead of the Survey of India, who definitely proved that the San-po and the Brahmaputra are one river. Since the annexation of Upper Burma a large part of the country has been surveyed and the wild regions to the north have been investigated. There is now little doubt that the source of the Irrawaddy lies in the unadministered hill country situated to the north of Myitkyina. It is, in addition, definitely ascertained that the eastern or main branch of the Irrawaddy, the 'Nmai Hka, rises in the Languela glacier in about lat. 29° N. on the mountain range which separates Putao from Tibet.

The course of the Irrawaddy can very well be divided into three divisions, in order of age :

1. The Upper Irrawaddy, the oldest.
2. The Lower Irrawaddy, which did not exist in the early Tertiary period.
3. The Delta (recent).

The Irrawaddy is formed by the junction of two streams, the 'Nmai Hka (Plate I, Fig. 2) and the Mali Hka. The eastern, the 'Nmai Hka, lays claim to being the main branch, though the western, the Mali Hka, actually means " Big River." It probably received its name from the fact that every navigable river is " big," but, in fact, although navigable, it is smaller than the 'Nmai Hka (Plate II, Fig. 1). In the following table measurements of the 'Nmai Hka and the Mali Hka, as taken by Lieutenant Blewitt about one mile north of the confluence, are compared :

| | 'Nmai Hka. | Mali Hka. |
|---|---|---|
| Breadth of water - - | 165 yards | 150 yards |
| Temperature - - - | 56° | 61° |
| Velocity of current - - | $3\frac{3}{4}$ miles an hour | $3\frac{3}{4}$ miles an hour |
| Sectional area of river bed - | 6,600 square feet | 4,000 square feet |
| Estimated volume - - | 32,257 cubic feet per second | 23,108 cubic feet per second |

Lieutenant Blewitt thinks that the velocity of the current may have been in both cases a little over-estimated, but nevertheless the figures seem to prove that the 'Nmai is the larger of

the two. This latter, rising from the Languela glacier, has several affluents, of which the Taron is the biggest. The grading of the bed is very steep, and the river rushes impetuously along at the foot of a thickly forested gorge. The Mali Hka rises in the hills surrounding the Hkamti-long valley in the old Putao district. The two streams join about 30 miles above Myitkyina, at a point known as the Confluence. Short stretches of the Mali Hka can be used by small boats, but actually neither river above the Confluence can be described as navigable, the courses being characterised by numerous rapids and falls.

The Upper Irrawaddy comprises the course of the river from the Confluence to where it is joined by the Chindwin in the Pakokku district. The river flows through certain well-marked, alluvium-covered basins, separated by belts of hilly country. The latter are composed of pre-Palaeozoic and Palaeozoic rocks of the Shan Plateau and the Northern Hill Ranges, and through them the river has cut its narrow channel; in places it is so constricted that defiles have been formed. There are three important *defiles*. The first or highest one is below Sinbo (see Plate III). The river is checked by ramparts of rocks, and enters a gloomy, savage and rock-bound gorge, 35 miles in length. This defile is narrow and tortuous; rocks in mid-stream, sudden abrupt curves, and seething whirlpools render navigation hazardous and difficult. At Sinbo the river is half a mile across, but immediately below the defile it is only 50 yards wide. At Pashaw, the Ruby Gate of the Irrawaddy, the width is again half a mile, and the river then flows calmly until a few miles below Bhamo it enters the *second defile*, which is not so narrow (Plate II, Fig. 2). Though set with dangerous eddies and whirlpools the current is not so strong as in the first; but the defile is perhaps even more picturesque and imposing. Steamers from Rangoon to Mandalay reach Bhamo throughout the year, despite the existence of this defile. Below this the river flows placidly and majestically again until it enters the *third defile* near Thabeitkyin, the river port of the Ruby Mines of Mogok. Here it follows a somewhat straight course through a narrow, moderately deep gorge with forested sides, but the passage is not so hazardous nor the scenery so beautiful as in the first two.

PLATE III.

THE FIRST DEFILE OF THE IRRAWADDY, NEAR SINBO.

Leaving the third defile at Kyaukmyaung in the Shwebo district the river follows a broad open course through the Dry Zone of Burma, where large areas adjoining it are occupied by alluvial flats. Opposite Mandalay it swings round the southern end of the Sagaing Hills, and, in an east-to-west course, cuts across the heart of Burma till it reaches the Pakokku district and is there joined by its great tributary, the Chindwin.

The Lower Irrawaddy may be defined as commencing below the confluence of the Chindwin and the Irrawaddy. From this point it winds somewhat lazily through the Dry Belt of Burma. There are few hills near the river, though the course itself is often bounded by high sandstone cliffs. It is interesting to notice that these sandy cliffs, such as those which are seen so well near Yenangyaung, are often capped by coarse red gravel, and sheets of gravel stretch over the plateau surface for an extensive area, thus indicating the once higher levels of the present river. Farther south, from Minbu to Prome, mountainous offshoots of the Arakan Yoma run down from the west to the bank of the river, and these leave but a small portion of the country fit for cultivation. On the east the country is also hilly, and spurs of the Pegu Yoma approach close to the river.

At Akauktaung, near Henzada, the river enters its famous delta, which forms an irregular triangle, having its apex about 180 miles from the sea, and with a curved base facing the sea. The sides of the triangle are formed by the Arakan Yoma on the west and by the Pegu Yoma on the east; the greatest width being about 150 miles at the arched base of the triangle. It should be noticed that at about the latitude of Henzada, the Pegu Yoma and the Arakan Yoma approach comparatively close to one another, being only about 80 miles apart; southwards they diverge again, leaving the broad stretch of the delta through which the waters of the Irrawaddy find their way to the sea through countless channels. One great offshoot of the main river, which leaves it about nine miles above the town of Henzada on the right bank, forms the Ngawun or the Bassein river, actually the westernmost of the distributaries. The easternmost stream of the delta is the Rangoon or Hlaing river. This is believed to have been a larger outlet to the Irrawaddy north of Prome, though it has long ceased to take

water from the main river there ; it now receives contributions through several smaller streams from the main river and also from the torrential streams of the Pegu Yoma, which form the principal source of its water to-day. Indeed, it must be noticed that many of the distributaries of the Irrawaddy which pass through the delta carry but very little water from the main stream to the Gulf of Martaban. This is true of the Bassein river, whose channel, where it leaves the main river, is 300 yards wide, but is choked by a sandbank uncovered in the dry season. From Bassein to the sea this is an arm of the sea rather than a distributary of the river. Indeed, with a wide and deep channel, free from shoals and dangerous passages, the Bassein river forms an excellent natural harbour, spoilt only by some rather sharp bends.

The distance between the mouths of the Bassein and Rangoon rivers, covering all the mouths of the Irrawaddy, is about 160 miles. Including the two above-named rivers, the Irrawaddy enters the sea by nine different mouths. The river divides and subdivides, converting the whole of the lower portion of its basin into a network of tidal creeks. The Rangoon river between Rangoon and the sea is a true marine estuary. Fortunately for the interests of the province, although there are difficulties in navigation, none is insurmountable at the entrance to the magnificent creeks of Rangoon. The river receives above Rangoon the Panalung branch of the Irrawaddy and the Hlaing river, while just below Rangoon the Pegu river and Pazundaung creek enter with drainage from the eastern slopes of the Pegu Yoma. All these are silt-bearing streams, and there is a large deposit of alluvium opposite the junction of the Pegu and Pazundaung rivers, forming what is known as the Hastings shoal, which is a great impediment to navigation. River-dredging operations have to be undertaken continuously at the port of Rangoon to keep the channel deep and navigable near the wharves.

## The Formation of the Delta of the Irrawaddy.

The delta of the Irrawaddy has been formed by the silting up of the shallow gulf of the sea by the detritus brought down

by the river, and the process was quite analogous to that which is still going on in the Gulf of Martaban. It is estimated that about 300,000 years ago the mouth of the river was somewhere near Prome, and even about 1,200 years ago the delta in its present form did not exist. The whole area was occupied by the sea, with islands, such as Twante, Myaungmya and Bassein, where laterite ridges stood above the water.

The effect of the tides in those days must have been felt above Prome; at present tidal influence barely reaches Yandoon. The delta is almost entirely composed of alluvium, except for the islands mentioned above; but there is a considerable area occupied by volcanic rocks in the Myaungmya district which are undoubtedly of Tertiary age. There is not the least doubt that the delta of the Irrawaddy is gradually extending seawards and the Gulf of Martaban is slowly silting up and getting shallower, and that the land is gaining on the sea. It is very difficult, however, to estimate the rate of advance of the delta in the absence of accurate maps of the coast line prepared at different times. At the present day the coast line takes the form of a belt of sand dunes, about a hundred yards wide, above high-tide level, and some three or four feet above the level of the land in the interior. Accretion does not seem to take place on the shore itself, but is due to the gradual formation of islands off the coast. Vegetation seizes upon the sandbanks whilst they are still below high-water level, and when it is established the subsequent silting is rapid and the sandbank becomes an island separated from the mainland by a shallow channel. The island enlarges with the spread of vegetation until it finally forms part of the main coast line.

Some idea of the rate of growth of the delta may be gained by studying the sub-surface contours of the Gulf of Martaban. Between long. 94° 45′ E. and 95° 30′ E. the 1909-10 survey clearly shows all the contour lines farther out to sea than they are in the survey of 1860-70. The 3-fathom line has advanced somewhat under two miles on the average, while the 5-fathom line is slightly over two miles farther out to sea. The 10-fathom line shows a mere advance of one mile, the 15-fathom line has extended slightly more than this, and the 20-fathom line has been projected seawards about three miles. East of long.

95° 30′ E. the 3-fathom line has probably also advanced seawards, but no records are available from which to estimate the amount. The 5-fathom line has advanced about one and a half miles off the mouth of the Rangoon river, but in an irregular manner. Most extraordinary changes have taken place farther out to sea if the original surveys are to be depended upon. The 10-fathom line has advanced an average of 10 miles, the 15-fathom line 20 miles, and the 20-fathom line 25 miles. The rate of advance of the fathom lines extending over a period of 100 years is tabulated below :

| Fathom Line | Mouth of the Irrawaddy, long. 94° 45′ to 95° 30′ E. | Gulf of Martaban, long. 95° 30′ to 97° 0′ E. |
|---|---|---|
| 3 - - - | 3·5 miles | ? |
| 5 - - - | 4·0 ,, | 5·0 miles |
| 10 - - - | 1·0 ,, | 14·0 ,, |
| 15 - - - | 1·25 ,, | 28·0 ,, |
| 20 - - - | 3·0 ,, | 35·0 ,, |

The coast line itself at the delta probably advances at a somewhat less rapid rate than the 3-fathom line. Three miles in a hundred years is a probable maximum.

In addition to the silting up of the delta, the whole country seems to have suffered a slight rise of the surface in late geological times, and it appears that the earth-movements affecting its level have not yet ceased.

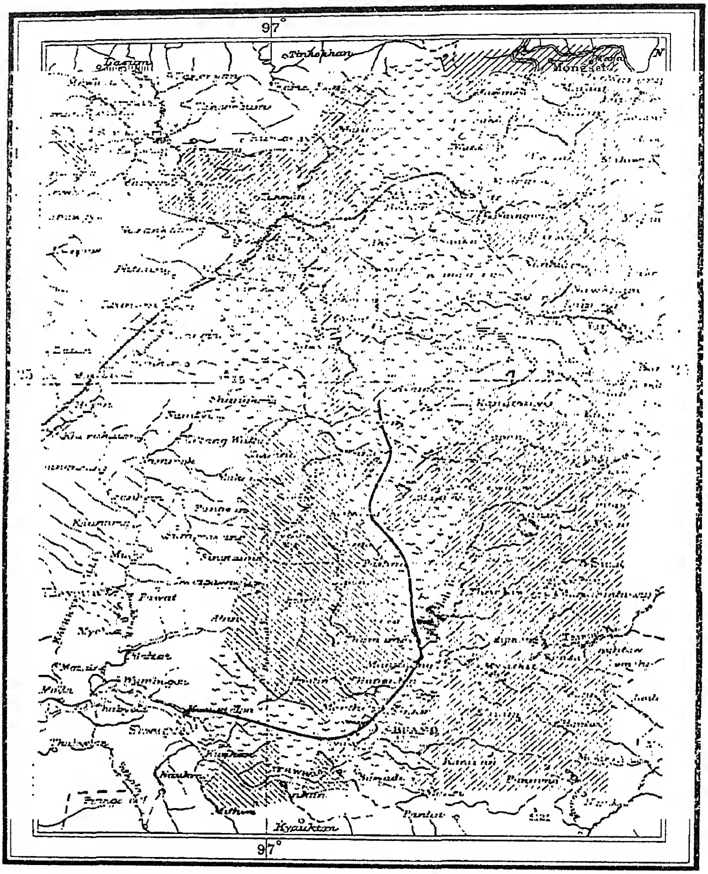
### Recent Changes in the Course of the Irrawaddy.

Not much can be said about the history of the Irrawaddy river, as large portions of the country to the north have not been studied in detail either geologically or geographically. There is no doubt, however, that the river is a very old one, and must have flowed several millions of years ago through the Northern Hill Ranges of Burma, with its mouth far north in Upper Burma. It has already been noted that during the Tertiary period a gulf of the sea extended into Upper Burma, and marine fossils of Peguan age (Mio-Oligocene) have been found as far north as the latitude of Monywa in the Shwebo

district. The mouth of the river cannot, therefore, have been far south of that locality. The river with its tributaries then silted up the gulf and drove the sea-water south until, by the end of the Tertiary period, about one-third of a million years ago, the gulf had receded as far south as Prome. Subsequently in the Recent and Sub-recent periods the delta was formed in its present topographical position. While these events have been happening there have obviously been changes in the course of the river itself. From the Confluence, and after a preliminary bend near Lapè, the river flows south in a fairly straight line to Myitkyina where it may be said to have left the Kachin hills. Its channel immediately widens to some 800 yards, and from Myitkyina to Sinbo, 72 miles by river but only 48 miles in a straight line, the Irrawaddy reaches a temporary base-level. Its valley bottom, only half a mile to a mile wide above Myitkyina, broadens to 16 miles. The deposits of the river are no longer gravel, but fine sand and mud.

A remarkable change in the nature of its valley takes place at Sinbo. All the way from Myitkyina the stream meanders quietly between low banks along a broad jungle-clad plain ; but a mile below Sinbo it plunges into the heart of the mountains—everything at this point, except the course of the waters, giving the impression of ascending rather than descending a valley. Half a mile wide in the plain, the river is confined in the entrance to this defile to a channel only 50 yards wide. In the great floods of the " rains " the turmoil of waters in the basin is indescribable. Even at Sinbo, a mile back, the waters rise 80 and 100 feet above low-water mark, and have been known to rise this amount almost in a single night. The general course of the channel as a whole is straight, but the valley ridges come down to the water's edge with an *echelon* disposition characteristic of the lateral valleys of virile streams ; also, studied in detail the course of the river is actually most tortuous, and sharp, right-angled turns, yielding most exciting moments to the navigator, are by no means uncommon.

Twelve miles east of the great defile and parallel with it for its total distance, is an open, flat valley, 10 to 12 miles wide near Bhamo, and untenanted by any stream of consequence.




MAP ILLUSTRATING THE FORMER COURSE OF THE IRRAWADDY BEFORE THE FORMATION OF THE SECOND & THIRD DEFILES.

*Geology from " Geological map of India & adjacent Countries " Scale, 1" = 32 miles. 1909.*

Metamorphic series

Alluvium

Basic intrusives

Gneiss & Mica schist

Tertiary

Former course of river

FIG. 3.

East of Sinbo it is nearly as wide and is then open to the broad Irrawaddy valley. Its levels are unknown, but there is no visible ridge at the head, and the divide, if one exists, can be only a few feet above the Irrawaddy level. From Alaw Bum (5,783 feet) on the Yunnan frontier, and 28 miles north-east of Bhamo, the whole valley plain from Bhamo to Myitkyina appears absolutely level and unbroken. From that height the Irrawaddy may be seen to disappear near Sinbo, and the eye looks vainly for its silver thread in the broad valley on the near side of the Sinbo hills. Yet it obviously flowed along that valley at no very distant time. Why then has it deserted it to flow through mountains 2,500 to 3,500 feet high, composed not of soft rocks but of hard metamorphic schists ? The answer is that the Irrawaddy waters have been captured by one of its own tributaries.

An examination of the topographical features of the country of the first defile reveals the history of its capture. Where the Irrawaddy formerly meandered peacefully at the foot of the Yunnan frontier hills, a tributary stretched from near Bhamo northward into the hills for a distance of some 30 miles. Beyond its head a stream flowed northward to join the Irrawaddy near Sinbo, as is shown by the general northerly direction of the tributary valleys. Near the Kachin village of Lema was the col. As both streams cut back their heads the col was lowered until the waters of the Irrawaddy at high flood burst over it, and, hampered by the lack of grade due to the meanderings on its old flood plain, gladly seized and deepened its new channel. It became, indeed, locally rejuvenated.

Below Bhamo also there have been changes. Nine miles west of Bhamo is a broad gap in the hills, through which the Irrawaddy formerly flowed. It was at that time that the coarse gravels of Mozit Chaung and Shwegu were deposited. The course of the old river bed is now occupied by the Thittaung Chaung. Here again there appears to have been domestic piracy, though the evidence is far from being as conclusive as in the first defile. The waters of the broad Irrawaddy valley seem to have been tapped near Sinkan by a small tributary, and there resulted the second defile, neither so long nor so dangerous as the first, but infinitely more beautiful.

Another remarkable recent change in the course of the river is to be seen about latitude of 22° 44′, where the Irrawaddy makes a sudden right-angled bend to the west, and flows westwards for about three miles before resuming its normal southerly course. The notable change in general direction in this region is determined by the presence of the lava plateau of Singu to the south, around the northern and western edges of which the river now swings. There can be little doubt that the lava was poured out across the valley and the river itself, and that the present course is comparatively recent. About halfway through this east and west stretch is the village of Kabwet on the northern bank. From Kabwet southwards the river gradually broadens out, but as far south as Singu, where the lava plateau ends, there is a marked contrast between the lava plateau on the east and the plain of Tertiary sands on the west. The plateau is a remarkable feature, and presents an almost level surface over about 24 square miles. Its edge presents a steep scarp to the river, its surface being upwards of 150 feet above river-level.

Another recent noteworthy change is the remarkable east-west bend of the river just below the latitude of Mandalay. There is not a shadow of doubt that the Irrawaddy first flowed through the valley now occupied by the Sittang, which may then have been a tributary to the main river. The east-west movements which especially characterised the close of the Tertiary period, aided by the upheaval of the Pegu Yoma with its northern continuation, caused it to change its course, and cut its way through the gap between the soft rocks of the northern end of the Pegu Yoma and the hills north of the river. It is probable that, as in the case of the first two defiles, a tributary of the then Chindwin captured the waters of the Irrawaddy by head erosion, and diverted the latter to its present channel.

**The Erosive Power of the Irrawaddy.**—It is remarkable that the Irrawaddy may be classed among the fastest eroding large rivers of the world. It has been estimated that it lowers the surface of the rocks of its basin one foot in about 400 years. This applies, not only to the chief river, but also to some of the smaller rivers of Burma, such as the Sittang, the Pegu,

etc., which accomplish an incredible amount of erosion, mainly during the rains. This extremely rapid erosion of the rivers of Burma is due to: (1) the soft friable rocks in the reception basins in the hills, it being noted that even the larger ranges, such as the Pegu Yoma, consist largely of soft friable sandstones and clays, with the result that they are highly susceptible to the excavating power of rainfall and rivers. (2) Heavy intermittent rainfall acting on steep slopes which form the edges of the river basin. The very heavy rainfall which falls in so many parts of Burma, ranging from 60 to 120 inches upwards in the well-marked rainy season of May-October, suddenly increases the volume of water in the rivers, which in turn increases the erosive power of the rivers, so that in flood they consequently accomplish a hundred times the erosion they perform during the low-water season. If the same amount of rainfall were evenly distributed throughout the year the erosion would be much less. (3) By the destruction of the protective covering of vegetation—the practice of *taungya*, or hill cultivation which is constantly shifting—by denudation of forests for timber, etc., removal of undergrowth, excavation of channels to float down timber, the land is freed from the binding action of vegetation, and the soft rocks are, therefore, easily cut away by the hill streams.

In addition to these three causes it must be remembered that the rivers of Burma (apart from their deltaic courses) are for the most part young. They are still in an immature state of development, and are ever busy in removing the inequalities in their courses and eroding or lowering their beds. This may be seen by the presence in so many parts of Central Burma of plateaux covered with gravels at considerable heights above the present level of the Irrawaddy, showing that at not very distant dates the bed of the river itself was at various higher levels.

The annual discharge of the Irrawaddy and some of its tributaries, the amount of silt carried, the time taken to erode one foot of land, etc., are compared with those of other important rivers of the world in the following table:

| River. | Drainage area in square miles. | Annual discharge in million cubic metres. | Total silt in tons. | Total dissolved matter in tons. | Annual lowering of surface in inches. | Time taken to lower one foot of land. | Remarks. |
|---|---|---|---|---|---|---|---|
| Mississippi | 1,224,000 | 544,700 | 406,250,000 | **112,830,000 | ·0042 | 2857·1 | From Russel. |
| Colorado | *225,000 | ... | *5,201,000 | ... | (2) ·0007 | 1714·3 | (2) For lower part of basin. |
| Danube | 320,300 | 196,000 | 63,000,000 | (1) 22,521,000 | ·0025 | 480 | From Pench. (1) Russel. |
| Rhine | ... | (3) 84,000 | (1) 8,400,000<br>(2) 64,000,000 | (3) 16,800,000 | ... | ... | (3) Pench. (1) At Bonn. (2) In Holland, calculated from data by Geikie. |
| Rhone | 34,800 | 58,800 | 36,000,000 | 8,290,500 | ·0124 | 833·3 | From Russel. |
| Po | 27,100 | 55,542 | 67,000,000 | ... | ·0263 | 458·3 | From Russel. |
| Thames | 3,670 | 2,074 | ... | 548,230 | ... | ... | From Geikie. |
| Nile | 1,100,000 | (1) 81,876 | (2) 73,950,000 | 16,950,000 | ·00085 | 1411·8 | (1) from Willcocks. (2) calculated from Mackenzie. |
| Ganges (Upper) | 143,000 | ... | 200,400,000 | ... | ·0149 | 805·4 | From Russel. (1) Geikie. |
| Irrawaddy, Prome | ... | (1) 424,160<br>(2) 445,100<br>(3) 524,000 | 236,000,000 | 48,340,000 | ... | ... | (1) Gordon's average. (2) 1909. (3) 1910. |
| Irrawaddy, Mandalay | ... | (1) 273,000<br>(2) 347,000 | 32,000,000 | ... | ... | ... | (1) 1909. (2) 1910. |
| Chindwin | 40,000 | 120,000 | 109,000,000 | 13,540,000 | ·0307 | 388·9 | |
| Mon | 1,960 | 2,840 | 5,500,000 | 428,000 | (1) ·0312 | 384·3 | (1) Lower than average for mid-Burma, because Mon rainfall is low. |
| Drainage of Irrawaddy between Mandalay and Prome | 80,000 | ... | 204,000,000 | 25,650,090 | ·0291 | 412·9 | |

After F. J. Warth.

**The Tributaries of the Irrawaddy.**—The Irrawaddy receives only three tributaries of note between the Confluence and Mandalay. Above the first defile near Sinbo the Mogaung river enters on the right bank, where its mouth is only 70 yards across; the Taping and Shweli join the main river from the left bank on the east. The sources of the Taping and Shweli lie between lat. 25° 38′ and 25° 50′ N. approximately, where the Shweli or Lung Kiang, as it is known to the Chinese, rises about five to ten miles north-east of the Taping. Above the Tali Fu-Teng Yueh road the Shweli is hemmed in a narrow valley, and has no tributaries worthy of mention. It is, however, a stream of considerable length and joins the Irrawaddy below Katha, just opposite Tigyaing.

The Taping river joins the Irrawaddy about a mile north of the town of Bhamo. During the dry season it is about 200 yards wide, while during the rains it is at least 500 yards wide and is navigable for about 20 miles from its mouth. It flows through the lofty mountains which lie north of Teng Yueh, and is augmented by a number of mountain torrents. It is noteworthy that it receives seven different names during its course of 150 miles.

Below Mandalay the Irrawaddy receives three other principal tributaries: the Nam-tu or the Myitngè, the Mu and, most important of all, the Chindwin. A detailed account of each is given below. There are also two small affluents, the Mon and Man, which should be noted as joining in the Minbu district.

**The Nam-tu or Myitngè.**—This is the most important river of the Northern Shan States, and drains a large part of that area; for a detailed account of the recent changes it has undergone we are indebted to the labours of La Touche. The Nam-tu rises in the state of North Hsenwi, in lat. 23° 20′ N., long. 98° 15′ E., within 20 miles of the Salween. At first it flows westwards to Meng-tat, in about long. 97° 30′, where it turns abruptly to the south and traverses the hilly country in a deep and very narrow valley. Below the hills it is joined by the Namma, which unites the waters of three considerable streams, two of which rise among the hills east of the plateau, within a short distance of the Salween. Below the junction of the

Namma and the Nam-tu, above Hsipaw, the combined rivers flow south of east to Bawgyo, where another tributary enters. According to La Touche there is some evidence to show that in former times the Nam-tu, instead of joining the Namma above Hsipaw as it does now, followed an independent course from the point where it leaves the hills at Tatiferry to Bawgyo. The original bed of the river seems to have been raised by an accumulation of boulders and gravel at the point where it leaves the hills, until it reached such a height that the river broke through the hills to the south-east, along a ravine excavated by two small side streams flowing into the Nam-tu and Namma respectively, and deserted its former channel.

At its confluence with the Nam-hsin, the main river turns once more southwards, and the valley gradually becomes deeper till, about 20 miles to the south of this point, it flows through a profound, narrow gorge whose sides may sometimes rise perpendicularly. Through this gorge the water rushes in a succession of famous rapids and long, deep and gloomy pools which rarely see the light of the sun. At the mouth of the Gokteik Gorge the depth of the channel is about 2,000 feet. It is joined from the south-west by a large stream, the Nam-Kha, in about lat. 22° 15′, and below this junction it again pursues a westerly course to the lower end of the Gokteik Gorge, where it receives the Nam-panshe. At this point the Nam-tu again turns due south for about 24 miles, and then flows westwards in a very winding course, to issue from the hills about 14 miles south-east of Mandalay.

La Touche is of the opinion that the course of the river is of very recent development, and it is interesting to note that its course is entirely confined to one formation—the Plateau Limestone. Throughout the gorge above Hsipaw the river flows parallel to a great overthrust fault, which strikes almost due north and south through the rocks at a short distance to the west. Spurs from the hills on the western bank slope down to the gorge, while on the east there is a steep scarp, which sometimes rises vertically from the water's edge to a height of 1,500 feet. Moreover, remains of old river terraces, consisting of water-worn boulders and pebbles, are found on the western slopes to a height of two or three hundred feet, while no such

deposit is to be seen on the eastern side. It seems probable that when the river assumed this direction and was flowing at a much higher level than at present, it took advantage of the great north-south fault and started cutting its course along it, following the general inclination of the strata, which is easterly, till it reached its present position, shifting its course eastwards. It appears also that the main river has captured the waters of its tributaries by head erosion, and has gradually invaded the valleys of the other streams and turned them into its own channel. La Touche arrived at this conclusion after observing the frequent and sudden changes in the course of the Nam-tu where, at almost every change, a considerable tributary joins the main river which then takes the direction of the tributary.

**The Chindwin River** in its upper reaches is known as the Tanai Hka, and rises near the Irrawaddy watershed in the Kachin hills in lat. 25° 40′ N. and long. 97° E., flowing almost due north until it enters the south-east corner of the Hukawng valley. It then turns north-west and continues in that direction, cutting the valley into two almost equal parts, until it reaches the north-western edge, when it turns almost due south. In the Hukawng valley it is joined by two important tributaries, the Taron and the Tawan Hka from the north. After leaving the valley it descends rapidly through a gorge with frequent rapids and waterfalls until it enters Singkaling Kanti, whence it preserves a general southerly course to its junction with the Irrawaddy some ten miles north-east of Pakokku. The Chindwin enters the main river by several mouths, the extreme outlets being 22 miles apart, while the intervals form a series of low-lying islands. According to tradition the southern mouth of the river is an artificial channel cut by one of the kings of Pagan.

Four miles below Homalin the Chindwin receives an important tributary on the left bank—the Uru river, which rises in the Myitkyina district and is the famous repository of part of the valuable Burmese jadeite. On the right bank it receives the Yu at Yu-wa (23° 35′, 94° 35′), and the Myitha at Kalewa, from which it receives the drainage of the Chin hills. Most of the tributaries from the east are auriferous. The main stream is

navigable by light steamers as far as Pantha throughout the year; in the rainy season the steamers ply up to Homalin.

A comparatively recent change in the course of the Chindwin is the result of volcanic eruptions along its course. At Shwezaye the calm, broad passage of the river across open country is interrupted by a barrier of cliffs of volcanic ash, through which the river cuts a narrow channel, only about 350 feet in breadth. These beds of volcanic ash were derived from the explosive craters of late Tertiary or Sub-recent age which occur on either side of the Chindwin at this point.

The Chindwin must at one time have occupied the present Lower Irrawaddy valley, which is in reality a continuation of the Chindwin valley. It is also probable that the Chindwin was once a bigger river than the Irrawaddy and flowed, continuous with the Sanpo (Brahmaputra) river, through the Hukawng gap; but the upper part was cut off by the Dihang, a tributary of the Brahmaputra, a change which is considered to have been facilitated by the subsidence of the Brahmaputra valley.

**The Sittang River** rises in the hills on the fringe of the Shan plateau in the Yamethin district, and flows due north for over 50 miles till it enters the plains, where it pursues a southerly course for over 300 miles before it pours its waters into the Gulf of Martaban. There is strong evidence that the Sittang valley was once occupied by the Lower Irrawaddy before it changed its direction westwards. The present Sittang is really the old, beheaded Lower Irrawaddy.

The Sittang is very remarkable for the strong tidal current or " bore " in its lower reaches. The estuary, which has a wide, funnel-shaped mouth, receives two currents of the tidal flow of the Indian Ocean. These unite, forming a huge tidal wave about 9 feet high, which moves at the rate of 12 miles an hour up the river and is very dangerous to navigation.

It should also be noted that the Sittang is a very unstable river and has frequently shifted its course, leaving old bends which ultimately form dry land. This will be made clear by a reference to the map (Fig. 4). Both the Pegu and the Sittang appear to have reached their base-level of erosion, and can no longer effect the vertical erosion of their channels. They only

possess the power of lateral erosion, and have become considerably shallower and wider; in their lower courses they are no

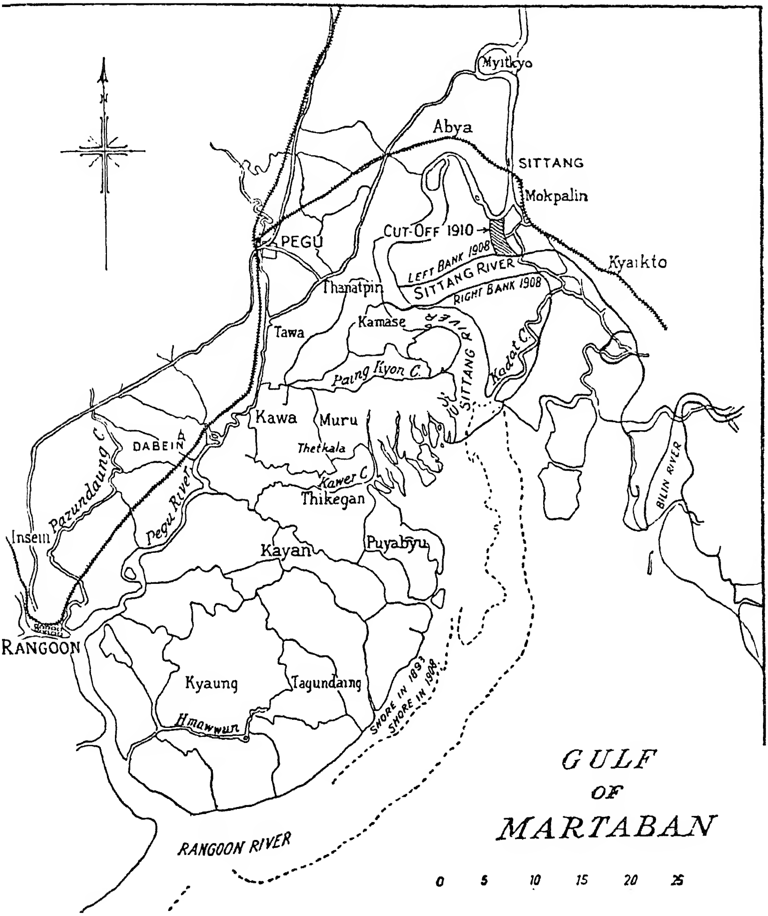



FIG. 4.—Map showing some of the recent changes in the lower course of the Sittang river.

longer eroding streams, but simply depositing ones. Consequently, some very important changes have taken place quite recently, and the river has deteriorated from the point of view of navigation in late years. About forty years ago the Sittang

had a deep channel and was only half as wide as it is now. It has silted up to such an extent that boats cannot navigate it in dry weather, and where, as at Toungoo, the depth of water was 18 feet before, it now varies from one and a half to four feet. This silting up is also accompanied by severe floods in the Toungoo and Thaton districts.

Large quantities of sand and silt enter the Sittang, being brought down yearly by the tributary streams and by the river itself from its upper reaches. Lateral erosion of its high banks at several places has necessitated the removal of villages (some as recently as a few years ago), whilst the silt so obtained is deposited on the river bed elsewhere.

The denudation of vegetation has caused a greater quantity of sand to enter than before. Sandbanks are found at the confluence of the tributary streams with the main river. All these cause progressive deterioration of the river, which has become shallower and wider, as well as unstable. It is continually shifting its course and forming large bends which interfere with the flow of water. This deterioration of the river results in a greater spill over the banks with consequent flooding, as the ground slopes away from them. The long and tortuous bends formed by the river are frequently cut across during the floods. A striking instance of this is seen near the town of Sittang where, in 1911, the river made a cut (Alok cut) across a long bend of 40 miles. The cut straightened the river, reducing its length and brought the sea much nearer than before. Consequently the sea has brought about considerable erosion of land in the Kyaikto subdivision of the Thaton district, and land has been added proportionately on the Pegu side as the shifting of the course of the river is to the eastward. These recent changes are shown on the sketch map (Fig. 4). The scour of the sea is now felt much farther north, and the severity of the bore action has steadily increased, destroying many old villages, such as Kyaukme, and attacking Sittang village itself, threatening the Sittang bridge.

**The Salween River** rises in the Tibetan Highlands. The true position of the sources of the Salween and the Mekong has not yet been ascertained, since our geographical knowledge of eastern Tibet is very imperfect, and Sir Sydney Burrard is of

the opinion that future surveyors will probably discover great errors in existing maps. He further states "the problem has been complicated by the convergence of the Salween, the Mekong and the Yangtze as they issue from Tibet. When the courses of three great rivers lie within 42 miles of one another it is hardly possible for an explorer to decide to which of the three a very distant feeder belongs, unless he follows the stream down. Hitherto explorers have only crossed the rivers at right angles, and none have yet succeeded in following their courses."

The Salween flows almost parallel with the Irrawaddy, and traverses the greater part of the Shan States in a succession of great gorges which are sometimes three and four thousand feet deep. There is no rift, defile or cañyon on the earth's surface of equal length. The Yangtze gorges are a mere fragment in comparison, and those of the Menam and Irrawaddy appear trifling. The average difference between the high and low-water level of the Salween throughout the Shan States is between 60 and 70 feet, and in some places as much as 90 feet. Until it reaches Lower Burma the basin does not anywhere reach two parallels of longitude in breadth.

The tributaries of the Salween in the Tibetan area are unknown. In Yunnan, where it is called the Lu Kiang, it occupies a long, trough-like valley. Closely compressed between the Irrawaddy and its tributary the Shweli on the west and the Mekong on the east, it receives no tributary except mountain torrents. In the Shan States the Namting, Namkha, Nambru enter on the left bank, and the Nampaing, Namtung and Nampan on the right. These last two streams are 250 and 300 miles long respectively. On the edge of the Thaton district the Taungyun, rising in the Dawna hills, joins it from the south-east. Farther down it receives the waters of the main tributaries, the Yunzalin from the north and the Gyaing and Attaran from the south-east. The river enters the Gulf of Martaban by two mouths, one west of Moulmein, the other 28 miles south of Moulmein. The latter is the more important, and provides access to vessels bound for the port of Moulmein.

According to La Touche, the entire course of the Salween is through Palaeozoic or Archaean rocks, unlike the Irrawaddy or the Himalayan rivers, which flow through plains composed

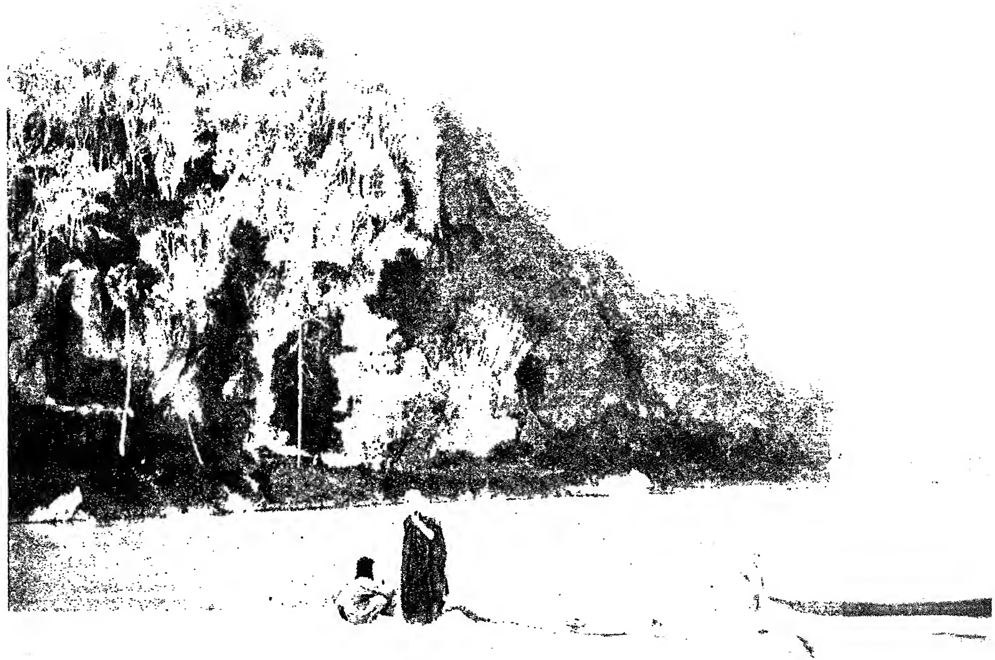
of soft Tertiary or recent deposits. It maintains the deep, rocky, trough-like character of its valley to within a few dozen miles of the sea at Moulmein (Plate IV). It is more effective, therefore, as a denuding agent than either the Irrawaddy or the Mekong, for these rivers lose their power of erosion when they reach the plains. The great depth of its valley compared with those of the Mekong and the Irrawaddy may be attributed to this cause. La Touche was of the opinion that on account of the tremendous depth of its gorge in places the Salween was of far greater age than the Mekong, but this has been proved to be incorrect. This depth is due to peculiar meteorological conditions, as the rains in that part come from the west; the Salween receives greater moisture than the Mekong, which helps it to erode its bed more rapidly. The narrowness of its valley is due to the encroachment of its neighbours upon its original drainage area. It is perhaps only the great depth of the valley which has saved it from being diverted into one or other of the channels on either side of it.

A remarkable feature of the tributaries of the Salween in the Shan States is that they usually enter the main river by a cascade or cataract. It may be partly due to a more rapid erosion of its bed than the side streams can keep pace with, but the more probable cause, as suggested by Sir J. G. Scott, is the enormous rise of the river during the rains, which is on an average between 60 and 70 feet. This rise would dam the waters of the side streams and cause them to drop their load of gravel and boulders at their mouths.

Some important but unfavourable changes—erosion of banks, formation of sandbanks, shoals and bars—have taken place in the lower reaches of the Salween within the last decade or two. They deserve mention since they seriously obstruct navigation. About fifteen years ago there were two navigable outlets from Moulmein to the sea. The northern channel, that between Martaban and Bilugyun, was then used by ships for eight miles from the sea. This has silted up, until now it is so shallow that even paddy boats have difficulty in navigating it in dry weather. During low tides in the dry season sandbanks are exposed, showing that the channel is practically closed.

Along the second or Amherst channel, which has ten bars and

PLATE IV.



is now used by ships, Moulmein is 28 miles from the sea. The worst bar is half-way between Moulmein and Amherst, and the water over it is only six feet deep at the lowest tide. The sketch map (Fig. 5) shows the unfavourable changes in the main channel and the consequent change in the course followed by launches.

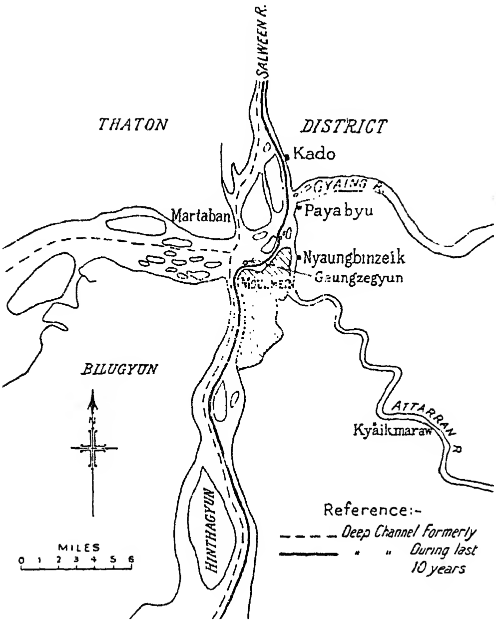



FIG. 5.—Showing recent changes in the mouth of the Salween river.

**The Parallel River System of Chinese Tibet.**—Eastern Tibet is drained by the Yangtze Kiang, the Mekong and the Salween, and on the surface of the plateau they flow at considerable distances apart. During their descent, however, they bend to the east-south-east and converge as if they were about to unite, then flowing parallel across the high plateau of Chinese Tibet for a distance of 170 miles, and for a greater part of that distance they are in a belt of country only 50 miles wide. Then they suddenly diverge. At Shihku the Yangtze starts to the east-north-east on an extremely zig-zag course through the mountains, and flows into the Pacific. The Mekong farther

south is diverted to the south-east; the Salween by a series of jerks to the west reaches the Bay of Bengal. The Salween and the Yangtze, in places only 42 miles apart, have their mouths separated by 2,000 miles. This is a very extraordinary feature of the river system of south-eastern Asia. Gregory explains this curious feature by suggesting that the south-eastern rim of Tibet was once a continuous range of mountains which turned the drainage into central China, whence it discharged into the Pacific; that the rim was cleft by earth movements and the rivers from Tibet flowed southward through the clefts until they reached old valleys to the south of the mountain rim and were diverted by them to east or west.

The valleys are tectonic and were formed in two stages: a high-level valley, broad and relatively shallow, was first formed; subsequently along its floor was cut a deep trough, which has been either left as a narrow canyon or enlarged into a broad valley.

**Evolution of the River System of South-east Asia.**—In Asia there is evidence of great east to west valleys; the Sanpo, the Hwang Ho, the Yangtze Kiang and the Si Kiang (west river) are probably the modern survivals of these ancient rivers. The Himalayan upheaval altered a great deal the general drainage from Tibet, for it left central Asia as a vast block with slopes to the east and south. The southern drainage after the close of the Himalayan movements was discharged by five main rivers.

1. The Dihang carried the drainage of the Sanpo and much of western Tibet southward through the broad Hukawng gap into north-western Burma; there it formed the Chindwin, which continued southwards as the Lower Irrawaddy.

2. The Upper Irrawaddy, which discharged to the sea as the Sittang river near Pegu.

3. The Salween then probably continued through the Maping and the Menam rivers to the Gulf of Siam at Bangkok.

4. The Mekong discharged more or less as at present, though it did not follow the same course.

5. The Yangtze (see Fig. 6).

This simple river system was broken up by subsidences,

probably as a result of reaction to the Himalayan compression. One subsidence resulted in the valley of Assam, which diverted the Dihang through the lower Brahmaputra to the Ganges;

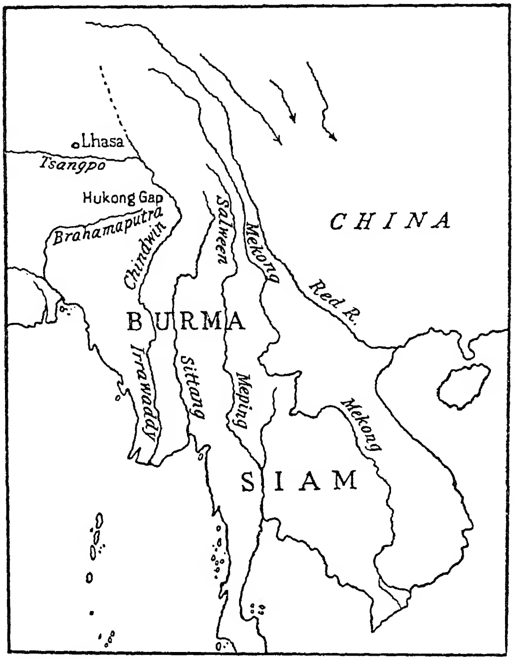



FIG. 6.—The post-Himalayan river-system of south-east Asia.

this change beheaded the Chindwin. The Salween was diverted by the formation of a series of young gorges westwards to the Gulf of Martaban (see Fig. 7).

**The Rivers of Tenasserim.**—The most important river is the Tavoy, which rises in the extreme north of the Tavoy district and flows slightly east of south for some 90 miles, draining about half the district. On its western banks it receives no stream of importance, all its main tributaries coming from the east. It is tidal to within 60 miles from its mouth, and its lower valley comprises most of the inhabited and cultivated land in the district. It is noteworthy that in this district all the main valleys are occupied by rocks of the Mergui Series, often in narrow strips with high granitic masses

on either side, and that the numerous granite masses are seldom crossed by important streams. According to Dr. Coggin Brown and Dr. Heron, the preference for the sedimentaries is so marked that the usual explanation seems inadequate, *i.e.*,

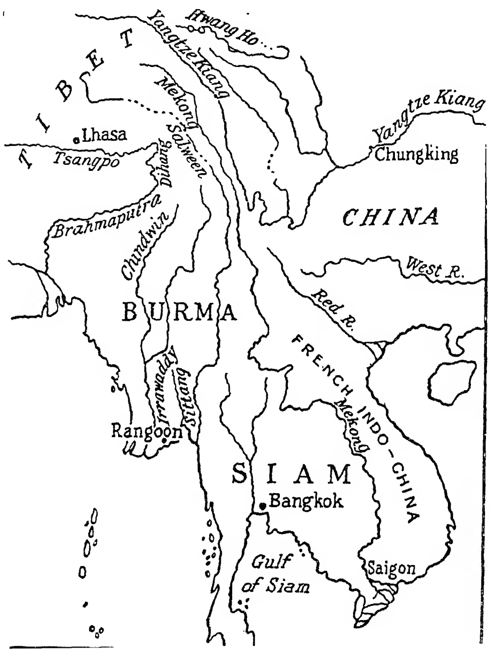



FIG. 7.—The present river system of south-east Asia.

that granite is more resistant to denudation than the sedimentary rocks. It is suggested that the main drainage lines in the Tavoy district are still along tectonic or original hollows, which originally lay between bulges in the upper strata.

In south Tenasserim there are three important rivers flowing in a north-south direction, a direction which is determined by the trend of the mountains. The biggest river is the Great Tenasserim, which is formed by the confluence at Myitta of the Ban and the Kamaungthwe. The former rises in the Myingmolekhat taung. After flowing north for about 50 miles it takes an inverted U-shaped bend, and then maintains its southerly course till it is joined by its important tributary, the

Little Tenasserim. The united rivers turn eastwards and then north-westwards, ultimately discharging their waters by two estuaries, one north and the other south of the island on which stands the town of Mergui. The other two important rivers are the Lenya and the Pakchan.

It should be noticed that the rivers, in order to reach the sea, have to cut through outer ridges of hard rocks, and consequently they form narrow and rocky gorges, usually with an east-west direction, near their mouths.

Besides these there are several streams draining directly into the sea, the watershed in the north being formed by a long north-south range. All these rivers, especially the Tenasserim and the Lenya, bring enormous quantities of sediment from the comparatively soft rocks which they traverse, and so tend to form deltas at their mouths. The delta of the Tenasserim river is just south of the island on which stands the town of Mergui. As the delta grows outwards towards the island, the sediments fill up the channels between the mainland and the nearer islands, with the result that the latter ultimately become part of the mainland and are separated from one another by narrow creeks and mud flats. Thus King Island is only separated from the mainland by a single navigable channel, Fell Passage, barely half a mile in width, and a few lesser channels with only one to four fathoms of water in them. Sellore is practically joined to the mainland, and Kisseraing Island has only a fathom of water between it and the coast, with a scarcely navigable channel between it and Domel Island. The position of these different islands is shown in Fig. 12, from which it can be noticed how the bed of the sea nearer the coast is being silted up by the sediments brought down by the river.

**River System of Arakan.**—The principal rivers of Arakan are the Kaladan, the Lemyo, the Mayu and the Naaf, which in general flow from north to south and are separated from one another by abrupt and lofty watersheds. The Kaladan, the largest and most important river, has its source in the Chin Hills, and is known there as the Boinu. Its course is at first southwards, then northwards, bending west as it passes through a portion of the Lushai hills and enters northern Arakan to flow southwards again. It empties itself, after a

course of nearly 300 miles, into the Bay of Bengal at Akyab, where its estuary is six miles wide. The estuary of this river is connected with that of the Mayu by numerous tidal creeks. The tide is felt as far north as Kondaw, 15 miles above Paletwa. Above this the river is a succession of rapids and shallows, whilst above the Sulla stream the bed is extremely rocky. It is a picturesque river, navigable for steam traffic as high as Paletwa, nearly 100 miles from the sea.

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# CHAPTER III

## LAKES

Burma has not many important lakes. The largest are in the north in the Katha and Myitkyina districts, the two chief being Indaw and Indawgyi. On the Shan Plateau there is the important Inle Lake, while in the Chindwin district are some interesting crater lakes. But in Lower Burma there are not many lakes of large size, although there are many ponds or marshes which become partly or wholly dried up during the hot season, and oxbow or cut-off lakes are common.

**The Lakes of Lower Burma.**—In Lower Burma, along the course of the Irrawaddy, the Sittang and other rivers, there are many small lakes. Shallow stretches of water, often only marshes, frequently drying up in the hot season, represent the deserted courses of the rivers themselves. Many of these lakes or marshes when drained make good paddy land. The principal lakes in Lower Burma seem to be of this type. The largest are the Engma or Imma lake in the Prome district, the Htoo and the Doora in the Henzada district, and a number of smaller ones in the Bassein district. The first named is in the south of the Prome district, and is about 10 miles long with a maximum breadth of four miles ; during the rains it has a depth of 12 to 15 feet, but in dry weather it is only a reedy marsh. Fed by the Zay on the north, it is the source of the Myit-ma-kha, which later becomes the Hlaing, and lower down the Rangoon river. The Htoo lake is in the Ka-noung township of the Henzada district, about eight miles from the right bank of the Irrawaddy. It is surrounded by low hills on the west and north. During the rains it receives some of the drainage from the Arakan Hills, but the banks of the lake are low and marshy and it is being gradually silted up. The Doora lake is in the

Henzada township, and is a little over two square miles in area.

**The Daga Lake.**—The Daga lake in the Bassein district, to which O'Riley gave the name of the "Lake of the Clear Water," has a circumference of about five miles and a depth from 20 to 45 feet in the centre. Its shape is irregularly oval, $2\frac{3}{4}$ miles long, and varying from half a mile to a mile in width. It is connected with the Daga river, which drains into the Ngawun or the Bassein river by a small channel about three-quarters of a mile long, which serves to replenish the water of the lake at the period of floods from the Irrawaddy during the south-west Monsoon, and carries off the surplus water on the fall of the river. O'Riley considered that the lake had been formed as a result of subsidence of the Tertiary shales and clays on which the lake rests. Theobald, who examined it later, regarded it as an annular depression which originally existed on the surface of the older alluvium on its first elevation from the sea, deepened, enlarged and brought to its present shape by atmospheric agency. Dr. T. Oldham, while commenting on the views of O'Riley and Theobald, said that it is simply an unfilled-in bend or, as Theobald says, "knuckle" of the river. Everything seems to be in harmony with this view, and Dr. Day in his work on fisheries in Burma was also satisfied that this was the true explanation of the facts.

**The Lakes of Northern Burma.**—The largest lake of Burma is the Indawgyi, in the far north in the Myitkina district. It is 16 miles long and 7 miles broad, and has an area of 80 square miles (Fig. 8). It occupies a depression hemmed in by low ranges of thickly-wooded hills on the south, west and east, and has an outlet on the north by the Indaw river, a tributary of the Nam Kawng or Mogaung river. According to tradition the lake was formed by an earthquake and submerged a Shan town. It is most probably of tectonic origin. Another large lake is Indaw in the Katha district.

**Nawng Yang Lake on the Frontier.**—The Nawng Yang Lake on the frontiers of Burma and Assam lies, according to Peal, at a level of 2,200 feet above sea-level. Looking from the pass southwards the valley extends as an irregular triangle for

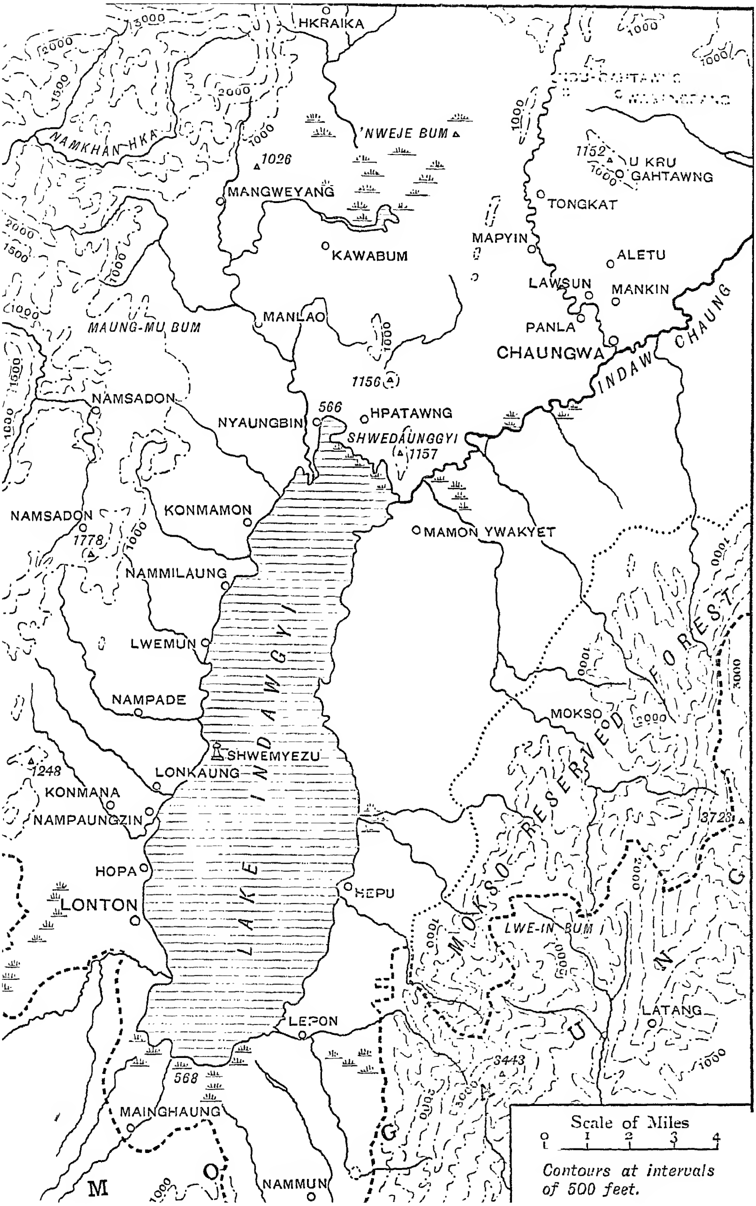


FIG. 8.—Map showing the Indawgyi Lake.

some eight or ten miles north and south, by three or four in width, the lake being near the Patkai end where broadest, and being itself approximately three-quarters of a mile long and half a mile wide. The banks are low and flat all around, and the bottom of the lake is covered with silt, there being no stones, sand or clay, while the outlet, Nawng Yang Pani, is from the south-east corner. Apparently the lake once filled the entire valley, the junction of its level with the hills all around being a well-marked line; the surface also mainly consists of grass and scrub jungle, and showing very few trees, is apparently all swamp.

It is interesting to note that Jenkins, writing in 1869, describes the lake immediately beneath the Patkai as an open sheet of water, perhaps three miles long, and exceeding a mile in breadth. Probably this discrepancy in the size of the lake given by these two explorers, visiting it at an interval of a decade, may be explained by the time of the year at which they visited. Jenkins visited it in December, while Peal was there in February, 1879. The lake may have been somewhat desiccated in ten years, and its size further reduced by evaporation from December to February, which are comparatively dry months. However, Peal spent a greater time on the lake, and his observations inspire more confidence.

**The Lakes of the Shan Plateau.**—Although there are now no important lakes in the northern part of the Shan States, it is believed that a considerable number formerly existed. They have gradually silted up, and at the present day their sites are marked by broad open plains, floored by comparatively young sedimentary rocks, often forming soil suitable for cultivation. Some of them are important, because amongst the sediments with which they have become filled in are minerals of value, including oil shales and lignite. In the southern parts of the Shan States one of the lakes formed in this way still remains; this is the Inle Lake.

**Inle Lake.**—This lake lies in the State of Yawnghwe on the Shan Plateau, at a height of 3,000 feet above sea-level in lat. 22° 35′ N., long. 96° 57′ E. The lake occupies the central part of a trough between two ranges of hills, which, like the ranges of that part of Burma, run almost due north and south. At its

two ends, and to a lesser extent on the western side, alluvial plains have been formed, and are gradually extending outwards into the water. Several streams run through the northern plain and combine in the swampy ground between land and water. One of the most important of them flows from the dried lake-basin of He-ho situated only a few miles to the north-west of the lake, but 800 feet higher. On the western side a rather large stream enters the lake by several mouths, coming also from the north-west, and rising in the high ground that separates the watershed of the Irrawaddy from that of the Salween. On the eastern side a few hill streamlets enter the lake; many of them dry up in winter, and all are very short. From the southern end a larger river makes its

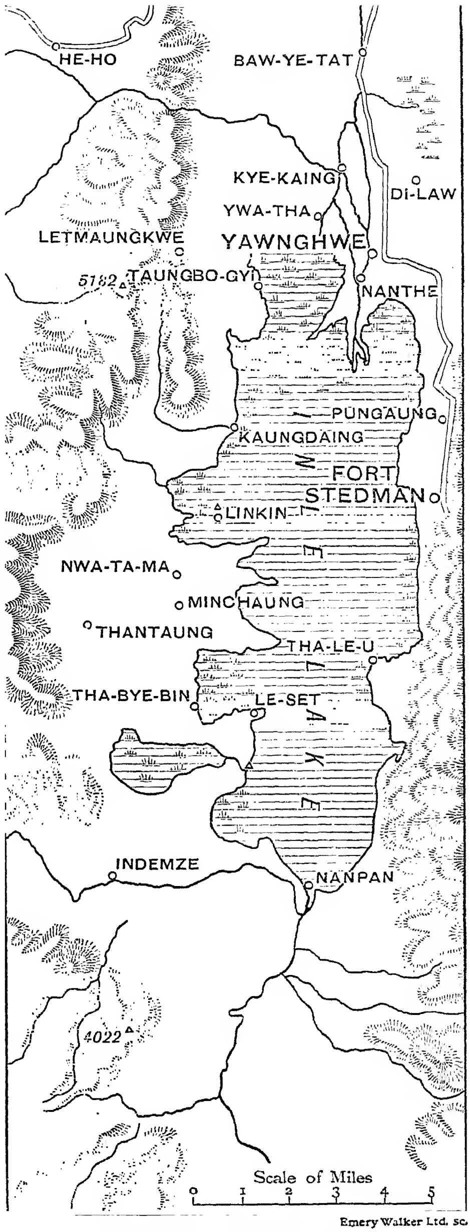


FIG. 9.—Map showing the Inle Lake.

way southwards; like the stream on the western side it disappears into the ground, but at some considerable distance south of the lake.

The lake is, in a sense, the centre of a closed system, without direct communication with any of the important river-systems of Burma, but, in a wider sense, it may be considered to belong to the water system of the Salween.

It is about 14 miles long and about 4 miles broad. The depth varies with the seasons. In March it is nowhere greater than 12 feet, and the average depth is not more than 7 feet; but at the end of the rainy season the greatest depth must be at least 20 feet. The bottom is overgrown with long and tangled weeds, which rise nearly to the surface. The water is remarkable for its extreme clearness. It is thus possible, when there is no breeze, to watch the animals at the bottom almost as if they were in an aquarium. All the silt brought down by the streams is deposited before it reaches the middle of the lake. No precise details are available as to the temperature of the water. Annandale found it remarkably constant at the beginnings of March, not varying more than 2° F. The average surface temperature was about 71° F. (21·7° C.) at that season, and the average bottom temperature one degree F. lower; the average air temperature being about 73° F. (22·8° C.).

It is impossible to state the exact dimensions of the lake because of two facts: firstly, because its size increases greatly in the wet season; secondly, because it has not at any time of the year what may be called a solid margin, for it is completely surrounded by floating islands formed by the growth and decay of vegetation. These islands, which are massed together round the edge of the lake, are one of its most characteristic features. The presence of the floating islands, cultivated or in their natural state, divides the lake into two regions, an open central region and the swampy marginal one. The faunas of these two regions, according to the late Dr. Annandale, are very distinct. He was also able to recognise an intermediate zone where the two regions meet.

**Origin and History of the Inle Lake.**—The lake belongs to the type known as solution lakes—lakes with their basins hollowed out of limestone by the dissolving action of water. The common

feature of such lakes is the presence somewhere in their bottom of a "sink," or a deep pit down which the whole or a part of the water is liable to disappear. No sink exists in the Inle Lake at present, but the point at which the river flows out of it and disappears underground may very possibly have, at one period, been beneath its waters. It is likely, however, that a very large tract of the country to the south of the lake must at one time have been covered by its waters and have been gradually filled in by the deposition of silt and the formation of peat, especially by the latter agency.

The lake must thus at one time have covered a much greater area than it does at present, and it must have been much deeper, though we may have no evidence as to the height to which its water reached. It may have been over a hundred miles long and several hundred feet deep. Moreover, it is by no means the only lake that once existed in the neighbourhood. Indeed, superficial deposits in the emptied basins scattered amongst the hills of the Shan Plateau make it evident that the country was once a regular lake country. Some of the lakes must have disappeared at a remote period, but others have dried up recently, perhaps even in historical times. There are traditions which seem to point to this having occurred at He-Ho. The deposition of silt and the formation of peat have not been the only factors that have led to the disappearance of water from the basins. Another cause has been the eating through of limestone by water rendered acid by the decay of vegetation. The He-ho stream flows down into the lower plain through an ancient limestone ridge, and it is not improbable that the water may have been finally drained from the upper plain by its cutting through its ridge in a comparatively short time under exceptionally favourable conditions.

**The Lakes of the Dry Zone.**—The Salt Lakes of Upper Burma tend to occur especially in the Dry Belt, and they owe their saline character to the rapid evaporation of the water, in the hot, dry season which characterises the Dry Belt of Burma. They occur especially in the Shwebo and Sagaing districts, *e.g.* Kadu, Halin, Mahanand and Thamantha in the former district and Ye-myet in the latter. The area of the Kadu lake varies with the season and has an average of four square miles. The

lake is only very shallow, reeds and grass being seen over the whole area. Another small lake occurs about seven miles due north of Sangaing, and is known as Yegan (bitter water). It is situated three miles south-east of Sage railway station, which is at mile 402 on the Mu Valley line. This lake lies in a hollow surrounded by hills. It yields brine for the manufacture of salt which smells strongly of sulphuretted hydrogen, and the constituents include sodium chloride (19·72 per cent.), and sodium sulphate (55·81 per cent.), in addition to others. The product is thus an impure form of Glaubers salt. It is manufactured by scraping off the deposit which forms round the dried exposed margin of the lake in the hot season. Mr. E. G. Robertson, Chief Collector, Salt Revenue, Burma, has suggested that the deposits in Yegan are worth the attention of those interested in the production of chemicals on a commercial scale. There are other smaller salt lakes in other parts of the Dry Zone, and also a number of shallow depressions which are filled by the overflow, during the high-water season, from flooded rivers, but which wholly or partly dry up in the hot weather.

**Crater Lakes of the Lower Chindwin District.**—In the lower Chindwin district there are excellent examples of crater lakes. At the present day there are seven or eight craters in all, and they occur roughly in a straight line on both banks of the Chindwin river about the village of Shwezaye. The distance between the most northerly and southerly craters, Ywatha and Leshè respectively, is about 13 miles. All the craters, however, do not enclose lakes. Amongst those situated on the east bank of the Chindwin, Twindaung is the only one containing a lake ; it is about two miles north-east of Shwezaye. Although this is not the largest crater in actual diameter it is the deepest and the most perfectly preserved. The inner slopes of the crater are everywhere precipitous, and wherever a footing can be obtained they are partially covered by vegetation. Lying some 300 to 400 feet below the rim of the crater are the still, dark waters of the lake, lapping the foot of the sheer crater face to the north and west. According to local inhabitants the depth of the lake in the centre is 74 feet. Sloping down to the water's edge on the east side is a narrow shelf of volcanic

PLATE V.

-VIEW ACROSS TWINYWA CRATER WITH "812" HILL IN THE BACKGROUND.

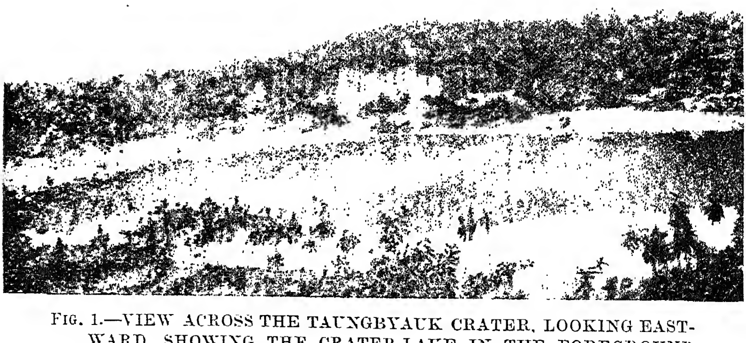

FIG. 1.—VIEW ACROSS THE TAUNGBYAUK CRATER, LOOKING EASTWARD, SHOWING THE CRATER-LAKE IN THE FOREGROUND AND THE LAVA WALL IN THE BACKGROUND.

ash, upon which the village of Twindaung has been built. It may seem peculiar that a village should be situated on the floor of a crater, but in this case it happens that the floors of the crater are below the level of permanent water saturation. In the Dry Zone of Burma there are seven months of the year practically without rain, and the water courses remain dry, except immediately after rain. The location of villages is therefore determined by the occurrence of a permanent water supply. Although the waters of the crater lakes are constantly replenished from springs issuing from the foot of the crater walls, evaporation proceeds so rapidly that the water is permanently green and stagnant.

About two and a half miles south from Shwezaye *taung* there is a group of three contiguous craters. Taungbyauk is the most northern of the three, and its crater measures approximately half a mile in diameter, and averages about 200 feet in depth. The floor is now partially covered by a small lake which is fed by fresh-water springs at its edge. The middle crater of this group is not so clearly defined as the others: there is no lake covering the floor, which has partly silted up and is now under cultivation. The Twin crater lake is the most southern of the group. It is the largest in diameter, measuring three-quarters of a mile across. It is shallow compared with its width, averaging not more than 150 feet in depth. The inner wall of this crater slopes gradually inwards to the edge of a lake, nearly half a mile across, which now covers the greater portion of the floor (see Plate V, Figs. 1 and 2).

With regard to the mode of formation of these craters, it is believed that they were formed by explosive eruptions, or, in other words, each crater is due to a series of eruptions of great violence but short duration when there was a violent explosion of steam or vapour which released the accumulated pressure underneath. The presence of such a lake is ascribed to the consolidation of the lake floor, by which it is rendered impermeable and so retains water. In the Lower Chindwin region the presence of a lake is due in every case to the crater pit having been excavated to a lower level than the local level of permanent saturation. In each case there is a continuous percolation of fresh water into the lake, whose level is kept down by

the great evaporation which goes on in the dry climate of this region.

Artificial Lakes.—The work of man in forming lakes must not be omitted. Of the important artificial lakes of Burma mention may be made of that of Meiktila (Plate VI, Fig. 1), constructed for purposes of irrigation by King Bawdapaya. The picturesque Victoria and the Royal lakes of Rangoon provide a favourite beauty spot which is one of the great amenities of the capital of Burma and the surface of these lakes is used for various water pastimes by the public of Rangoon. Formerly Rangoon used to obtain its water supply from the larger of these lakes, but now gets the bulk of that supply from another artificial lake considerably farther north, and known as Hlawgaw. Similarly, many of the villages in Burma have artificial lakes for the purpose of sustaining a water supply throughout the year; whilst in other places the lakes are in the nature of tanks, so common in India, from which water is drawn for irrigation purposes.

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PLATE VI.

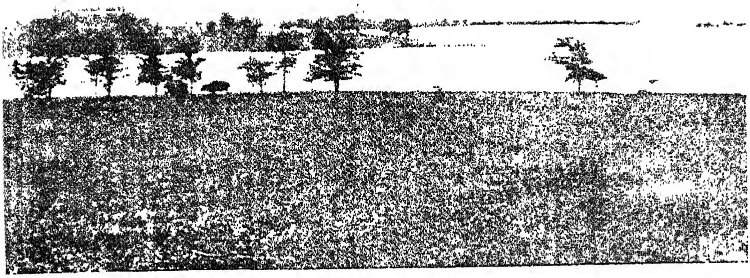


FIG. 1.—THE MEIKTILA LAKE.

G. 2.—RAISED BEACH AND OLD SEA-CLIFF, MYINBYIN, WEST COAST OF RAMRI ISLAND.

# CHAPTER IV

## EARTHQUAKES

BURMA is a part of the Extra-Peninsular region, which also comprises the young fold mountains of the Himalayas and the hill ranges of Afghanistan and Baluchistan on the west. All this area forms part of a weak and flexible zone of the earth's crust which has not yet attained its final state of equilibrium. That these folding movements have not yet ceased is proved by the frequent occurrence of earthquakes. Indeed, minor quakes are felt not infrequently in Rangoon, and few years pass without some records. These may be associated with the almost continuous folding of the ridge on the southern end of which stands the Shwe Dagon Pagoda.

Volcanoes tend to act as safety valves and to relieve the strain and pressure ; it is to be noted that a number of extinct volcanoes occur in the Central Belt of Burma. Dr. Coggin Brown, in his introduction to the account of the Burma earthquakes of May 1912, wrote as follows :

" Beyond the date of a few earthquakes which occurred in Burma during the latter part of the seventeenth and eighteenth centuries, and the meagre details of the effects of two or three of them as collected and recorded by T. Oldham in 1883, practically no information exists about the seismic disturbances which universal traditions of the Burmese people assert to be frequent and severe in many parts of their country."

The largest lake in Burma, Indawgyi, according to tradition is said to cover a large Shan town which is believed to have been destroyed by an earthquake. That these traditions are likely to be true is suggested by the intense folding, as seen in the mountains of the province, and by a consideration of the more recent geological events.

The earliest earthquake on record, which affected Burma, took place at 5.0 p.m. on 2nd April, 1762. It was very violent and destructive, and was felt all over Bengal, Arakan, etc., chiefly and more severely in the northern part of the east coast of the Bay of Bengal. The effects of this earthquake, causing, according to Halsted, an elevation of the coast of Arakan, are given in the sequel, though Mallet was inclined to be sceptical about his observations.

**Ava Earthquake of 23rd March, 1839.**—A very serious and destructive earthquake within Burmese limits occurred on 23rd March, 1839, the details of which were collected by Dr. T. Oldham, the founder of the Geological Survey of India. The shock was felt throughout the whole Burman Empire from Bhamo to Rangoon, and even as far as Siam. This earthquake caused such terrible destruction that evidences of it were very marked at the time of his visit, sixteen years after the actual occurrence; so much so that the Pagoda of Mingon, doubtless one of the largest masses of solid brickwork in the world, was utterly shattered. The Rev. E. Kincaid has described some of the havoc played by this earthquake. He said that in the morning not a pagoda was to be seen standing intact. Every brick building in the town had either been thrown down, burying beneath it numbers of people, or had been damaged so severely as to render its demolition necessary. The pagodas crowning the hills of Sagaing shared the same fate as those at Amarapoora. The following are some of the extracts from Mr. Spear's account given in response to Dr. Oldham's inquiries:

"On Saturday morning, 23rd March, 1839, at about 4.0 a.m., Amarapoora was visited by an earthquake that surprised the oldest inhabitants by its violence. Burman history mentions nothing of the kind having taken place before. I was in bed and asleep at the time, but was soon awoke by a tremendous roar, and the tiles from the roof of the house coming down about my ears; the motion was so great that I had some difficulty in finding the door, but whether vertical or horizontal I had not presence of mind sufficient to judge at the time. I did not even know it was an earthquake until it was finished. The shock may have taken up about thirty seconds in all.

"When I did get into the open air, I found the heavens with-

out a cloud, and although there was not a breath of wind, the trees shook as if it were blowing a gale. The dust rising all round from the destroyed houses gave the sky a peculiar appearance, not easily to be forgotten.

"From the appearance the ruins presented in the morning I have little doubt the motion was from north to south. The river did rise a little, as if its bed had been obstructed, but did no damage to the boats, not even to those that were deeply laden. I never heard of a wave, but the banks of the river between Amarapoora and Ava were rent in many places, presenting chasms of from five to twenty feet in width, from which large quantities of water and sand of a blackish appearance had been ejected.

"Judging from the appearance the city walls of Amarapoora and Ava presented the next morning after the great shock, I am decidedly of opinion that it must have been felt stronger in the latter than in the former city.

"At Sagaing, I would not say that it was stronger than at Ava, either on the hilltops or on the river-side. My reason for supposing this is, that the pagodas on both sides of the river presented the same appearance: that is, they were all deprived of their '*htees*' (umbrellas of the Burmese pagodas), and the same quantity of brick-work from the top.

"This earthquake was felt at Bhamo and Rangoon; in fact, all over the Burman territory. In Rangoon, the time observed was very nearly the same as here; it did no damage, but was strong enough to ring pagoda and some house bells, and alarm the inhabitants.

"From all that I have been able to learn, I think Ava must have been about the centre.

"After the great quake, we had strong shocks all day, every five or twenty minutes, but none coming up to the first in violence. They were, almost invariably, preceded a second or two by a sound resembling a cannon fired at a distance; or, at other times, as if a number of carriages were passing over a rough bridge underground. There were two distinct kinds of earthquakes: that preceded by the cannon-like sound had little or no rolling motion, but more resembled someone thumping up from below, as it were; it made the houses 'dirrl' and set the slates and

glasses a-dancing. The other came like the wave of the sea, with a motion generally from east to west; at least, that was my impression at the time. *Underground sound seemed to come always from the eastward.*

"For four or five days we had nothing but earthquakes every fifteen and thirty minutes; and for six months after, scarcely a day passed without one. In fact, it is only the last three years that we have been tolerably free from them. There never was a correct list of the number of people killed; but there must have been from three to four hundred. Ava suffered most from having some brick *Kyaungs* (monasteries) where a great number of *Poongyis* (Burmese monks) were destroyed."

This earthquake was felt at Moulmein, and for a distance of a thousand miles from north to south. At the same time a sharp shock was felt at Kyaukpyu, followed immediately by a magnificent burst of fire from the hills, with mud volcanoes to the south-west of the station. The flames continued to rise and fall in huge jets for half an hour, accompanied by reports resembling the discharge of distant artillery.

In a manuscript journal of Captain McCleod, in the Foreign Office, Calcutta, there is a brief account of this earthquake:

"At about half-past one this morning (23rd March, 1839) we were suddenly roused from our sleep by two terrible shocks of an earthquake. Though numerous concussions continued to take place, none were so severe as the first two. In the morning not a pagoda was to be seen intact. Every brick building in the town had either been thrown down, burying in their ruins numbers of people, or rent and damaged so as to render their being taken down necessary.

"The pagodas crowning the height of Sagaing shared the fate of those of Amarapoora. In the neighbourhood of the Residency extensive and deep fissures had spread out, from which large quantities of water had been discharged, and the earth in many places hove up with water springing up from the centre. The wells were all choked up and dry."

**Kyaukpyu Earthquakes of 1843 and 1848.**—The next earthquake on record occurred at Kyaukpyu at 11 p.m. on 6th February, 1843. It caused magnificent eruptions from the mud volcanoes and slight tremors at Ramri, lasting till 1 o'clock

in the morning. Another earthquake in the same year, on 30th October at 7.45 a.m., was more violent, but lasted only two minutes. It was felt only slightly at Ramri, but more severely at Cheduba. On 3rd January, 1848, another earthquake at at Kyaukpyu damaged the civil magazine, as well as other buildings.

**Earthquake of 1858.**—Two slight earthquakes were felt at Amarapoora on 18th September and 5th October, 1855, but that of 24th August, 1858, was much more destructive. The shock was most severe near Thayetmyo and Prome, though it extended as far as Rangoon and Moulmein, where, however, very little damage was caused. It decreased in intensity southwards, and the general direction appears to have been from east-north-east to west-south-west. The time is reported to have been 3.38 at Thayetmyo and 3.45 at Rangoon. At Henzada tops of pagodas were knocked down or canted over. At Prome the shock, which was sharp and severe, lasted almost a minute. One observer distinctly noticed the eastern end of his house raised first and then the western one. In the more northerly localities houses collapsed and tops of pagodas were torn off. At Thayetmyo three distinct waves preceded by a rocking motion of short duration were felt. Some persons who were in the open experienced a current of hot air and a rushing sound as of a large flight of birds immediately preceding the shock. The rumbling and clattering noise was instantly followed by a vibrating movement, which in its turn was almost immediately replaced by the passage of the first earth wave which threatened the destruction of every house. The houses rocked considerably and most of the pagodas were badly damaged, their tops falling to the south-west, while several were entirely reduced to ruins. The north wall of a pagoda near the Assistant Commissioner's house was separated from the main body of the structure by a wide chasm. The steamer *Diana*, lying at the ghat in comparatively deep water, felt "as if driving in a gale of wind." She swung completely round with her bows pointing downstream, and remained so till reversed and restored to her proper direction. Mud was brought up to the surface of the water in the north of the cantonment where the river is shallow; the bed of the river

was distinctly seen to rise out of the water, and to resume its old level after the shock had passed. There was a partial eclipse of the moon the same evening.

The shock was slightly felt at Ava. At Akyab the motion was said to be from south to north and to have lasted about a minute and a half. It was, as usual, severe, as it dislodged bricks from the walls of the Collector's office. The Principal Assistant at Ramri reported the entire disappearance of False Island, situated south-east of the island of Cheduba, lat. 18° 38′ N., long. 93° 55½′ E., no trace of it being seen after the 24th August. He considered its disappearance was due to the earthquake. Two earthquakes, apparently the after-shocks of the one just described, were felt on 26th August at 8.30 a.m., and 27th August at 9 a.m., at Prome and Thayetmyo respectively.

On 23rd July, 1864, two shocks were felt in Rangoon, but no damage was done. The earthquake was felt slightly in Thayetmyo. Daily shocks are reported to have been felt in Mandalay in the end of August and beginning of September 1858.

**Mandalay Earthquake of 16th February, 1871.**—Halsted published a brief account of the earthquake which was felt at daybreak of the 16th February, 1871, in Mandalay in two successive and gentle shocks. It did no damage.

In 1874 a severe earthquake occurred in the Southern Shan States, and its effects there were widespread. Another earthquake of moderate intensity occurred at Rangoon on the 23rd of July, 1884. Two shocks were felt, doors were rattled, etc., but no damage was done. It was also felt at Thayetmyo. On 6th January, 1868, a slight earthquake was felt at Moulmein.

**Earthquake of 31st December, 1881.**—On the morning of the 31st December, 1881, an earthquake, which is believed to have originated in the Bay of Bengal, west of the Andaman Islands, was felt over an area of 2,000,000 square miles. Besides affecting a large portion of the Indian Peninsula and Bengal, it was also felt on the Burmese coast, including some of the islands in the Mergui Archipelago, and caused much damage in the Andaman and Nicobar Islands. The surface of the ocean was greatly disturbed, and waves were formed which continued to

roll against the coastlines for several hours after the cessation of the earth waves, which lasted only for a few seconds. The first tidal wave was recorded at Port Blair at 8.10 a.m., followed by others in succession at about 15 minutes' interval, with a height of about three feet from crest to hollow. They continued till 9 p.m. The velocity of the waves, as computed by Major Rogers, varied from 2 to 6·9 miles per minute. At Rangoon, Moulmein and various points in the Mergui Archipelago the earthquake was distinctly perceptible, though much less violent; but no trace of a sea-wave was met with at any of the tidal stations in this quarter; the belt of islands and shoals which extends from Cape Negrais to the island of Sumatra, practically dividing the Bay of Bengal into two portions, must have formed a barrier to the sea-waves, for, though great and numerous at Port Blair, they died down in the deep sea beyond and in no case reached the eastern coastline. The sea-wave perceived was positive, the crest preceding the trough and raising the sea-level.

**Burma Earthquake of May 1912.**—In May 1912 Burma experienced some very severe and serious earthquakes. The main one occurred on 23rd May, 1912, but it was preceded by two lesser shocks, the first occurring on 16th May. It happened at about 3 a.m., and appears to have affected the western portions of the Northern and Southern Shan States. Its intensity on the Rossi-Forel scale did not exceed V.

The violent earthquake of 21st May appears to have shaken the whole of the greater part of the Northern and Southern Shan States and the districts of Mandalay, Ruby Mines, Shwebo, Sagaing, Lower Chindwin, Kyaukse, Myingyan, Meiktila, Magwe, Yamethin, Toungoo and Pegu, as well as northern Siam. The minimum area over which it was felt approximates, therefore, to 125,000 square miles. In the central parts of the area an intensity of at least VII on the Rossi-Forel scale was attained, and sometimes loud rumbling noises accompanied the shocks, but the intensity appears to have died away rapidly. This shock took place at about 3 p.m., and was followed by continuous after-shocks during the remainder of that and the following day in Maymyo, Mandalay, Taunggyi, Kyaukse and elsewhere, and which gradually became fewer, until the great earthquake on the morning of 23rd May, which was

sensible over an area of approximately 375,000 square miles, and disturbed recording instruments throughout the world. The most severely affected area lay partly in the Northern Shan States, the Ruby Mines, Mandalay and Kyaukse districts, and partly in the Southern Shan States. By far the larger area lay within the plateau of the Shan States. It was followed by innumerable small after-shocks during the three succeeding months, till they gradually became fewer and finally ceased.

It is remarkable that the earthquake of 1912 resulted in practically no loss of life, while damage to property was incomparably smaller than that caused by similar shocks in other parts of the world. This was due to the scanty population in the affected areas and the character of the dwellings.

Reports from Maymyo stated that nearly every year about this season the town, in common with other places in Upper Burma, is visited by an earthquake, the last big one being in 1908. As mentioned before, the first two shocks of the 18th and 21st May were felt at Maymyo, though they caused little damage. The most severe tremor was felt at 9 a.m. on 23rd May, when considerable damage was caused in all parts of the town. It could be heard approaching from a distance with a sound like low thunder, accompanied by the crash of falling bricks and plaster, while nearly every brick building in the town suffered. There were, in addition, huge landslides, and on the Northern Shan States branch of the Burma Railway embankments fell in and rails were bent. Throughout the day slight shocks continued, rather like violent tremors.

At Mandalay a severe shock was felt at 9 a.m. on the morning of the 23rd May. It lasted about a minute and caused much damage. A number of brick buildings were badly cracked, some of them losing their upper portions altogether, while their inmates bolted into the open. At Taungdwingyi the duration of the shock was more than a minute, and buildings in the town were considerably damaged; almost every chimney toppled down or was cracked.

At Mogok numerous fore-shocks were felt, but the greatest damage was done on the 23rd. Nearly every brick building in the town was cracked, and about 60 pagodas collapsed. The shock, it appears, was felt all over Burma, from Mergui district

in the south to the northern frontiers. Reports of the tremors were received from several towns in Burma, the Shan States and from Siam. At the same time slight quakes were also reported from Teng Yueh in Yunnan, and from several towns in Northern India and Siam, showing the wide extent of the main earthquake.

The maximum intensity of the shock, experienced in the neighbourhood of the Kyaukkyan fault, east of Maymyo, was IX on the Rossi-Forel scale. The railway lines were bent in a smooth curve close to the actual line of the fault, while cuttings and earth banks in the vicinity had slipped and blocked the line. Cracks in the cliffs near Myinpyu emitted streams of mud and water which were sufficiently voluminous to overwhelm or partially destroy Shan houses. Fresh cracks opened in the ground on Myinpyu hill and elsewhere. Near the northern end of the fault landslides occurred up the Nam-pan-se stream, but after a time the water forced its way through the barrier. The innermost isoseismal line encloses an area of about 36,000 square miles, the greater portion of which experienced an intensity of VIII on the Rossi-Forel scale. The longer axis of this oval runs in a general north-south direction, and the area affected includes the whole or greater parts of the districts of Mandalay, Sagaing, Kyaukse, Meiktila, Yamethin, Shwebo and the Ruby Mines, small portions of Bhamo, the Lower Chindwin and Myingyan, together with a very large part of the Northern Shan States and a corner of the Southern Shan States. The intensity gradually decreased outwards from this oval.

**Cause of the Earthquake.**—The majority of tectonic earthquakes are believed to be due to vibrations produced as a result of the folding and faulting of strata, or of any slipping along the previously existing faults that constitute weak planes in the earth's crust. Dr. Coggin Brown has shown that the movement along the great Kyaukkyan fault gave rise to the earthquakes in question, adducing the following arguments in support of this view.

1. The major axis of the elongated oval enclosed by the innermost isoseismal line coincides very nearly with the Kyaukkyan fault in the Northern Shan States.

2. A relationship is evident between the places where the maximum intensities were experienced and the greatest damage done and the known course and probable continuation of that fault.

3. The railway was bent close to that point where it crosses the Kyaukkyan fracture, but was quite undamaged where it traverses other faults of the plateau.

**Pegu Earthquake of 5th July, 1917.**—An earthquake of some intensity was felt in parts of Lower Burma on the 5th July, 1917, at about 4.40 a.m., when the moon was in total eclipse. Unfortunately the data available are very meagre. The only damage reported occurred to the famous Shwemawdaw Pagoda at Pegu; its umbrella or *hti* with all the jewels, worth many thousand pounds sterling, was shaken down and destroyed several smaller pagodas at its base.

**The Rangoon Earthquakes of September and December 1927.**—Three smart earthquake shocks were experienced in Rangoon on the 10th September, 1927, at 12.5 p.m., 12.47 p.m. and 4.25 p.m. (Rangoon time), but none of them did any appreciable damage. In the early morning of 17th December, at 2.25 a.m., a much severer shock occurred, which caused widespread alarm and a certain amount of damage. It attained an intensity of VII on the Rossi-Forel scale in Rangoon, and did a certain amount of damage to buildings in this city. It was felt over an area of 5,000 square miles, comprising the districts of Hanthawaddy, Insein and Tharrawaddy, and also the Maubin and Yandon townships of the Maubin district and the Dedaye township of the Pyapon district. Its duration was believed to be between 5 and 6 seconds. Such earthquakes are believed to be of a local tectonic nature, but most of the affected area is covered with alluvium which effectually hides the structure of the rocks below it. However, there is much evidence that the Irrawaddy delta and the hilly regions bordering it are not quiescent, in the sense that they have not attained permanent stability. It is concluded, therefore, as probable that the Rangoon earthquakes originate in forces of uplift causing movement along lines of weakness below the deltaic alluvium. It seems possible that one of these lies not far below the surface in the vicinity of Rangoon. Dr. Coggin Brown has published a

detailed account of the shocks, and the interested reader is referred to the *Records of the Geological Survey of India.*

The year 1930 was distinguished in Burma by an exceptional number of disastrous earthquakes. The first of these was the great Pegu earthquake of the 5th May, followed by the series of severe earthquakes round Pyu in the Toungoo district on the 3rd and 4th December. The three earthquakes of Swa on the 8th of August, 1929, and the Pegu and Pyu earthquakes of 1930 all probably form part of the same series of events, for their epicentres lie approximately in a straight line, and appear to be connected with movements of the boundary fault of the Shan plateau or of some other dislocation related thereto and lying slightly farther to the west.

**The Swa Earthquake of 8th August, 1929.**—On the 8th of August, 1929, a very severe, but local shock occurred, which seems to have had its epicentre a few miles west of Swa in the Toungoo district. Here a metre-gauge railway belonging to Messrs. Steel Bros. & Co. was severely damaged. In places the track was twisted and bent, fishplates and bolts snapped, bridges and culverts collapsed, the sides of cuttings fell in, loaded trucks were turned upside down and coolie huts shaken to pieces. This earthquake was reported from Yamethin, Pyinmana, Yenangyang and Tharrawaddy.

**The Pegu Earthquake of 5th May, 1930.**—The Pegu earthquake which took place at about 8.18 p.m. on 5th May, 1930, caused the practical destruction of the town of Pegu with a loss of at least 500 lives ; it also caused many deaths and great damage to property in Rangoon. It was sensible to human beings as far as the Kyaukpyu and Mergui districts up and down the coasts respectively, as far north as Mongmit in the Northern Shan States, across the greater part of the Southern Shan States and the Kingdom of Siam. The outer curve marking these approximate limits passes into the Bay of Bengal, the Andaman Sea and the Gulf of Siam, but the land area actually involved was not less than 220,000 square miles. The shock was registered by recording instruments at seismological stations in every part of the world.

The author had the privilege of being associated with Dr. Coggin Brown and Mr. Leicester in the investigation of this

disaster of the first magnitude, and a preliminary account was published in the *Records of the Geological Survey of India.* The region of maximum intensity lies within isoseismal IX on the Rossi-Forel scale, and embraces 375 square miles within the Pegu and Hanthawaddy districts, stretching in an elongated pear-shaped area south of Pegu itself to beyond Thongwa—a distance of 45 miles as the crow flies. At Pegu itself a considerable portion of the town was ruined, and fire, which broke out at once, added to the horror of the situation. Large cracks appeared in the ground and exuded sand and water. Big pieces of the river bank slid into the stream. Within the epicentral tract the Tawa lock of the Pegu-Sittang canal, together with the adjoining country, was raised by 0·77 feet.

**Cause of the Pegu Earthquake.**—The epicentral tract of the Pegu earthquake lies in the Pegu plain south of the Pegu-Sittang canal. It consists of low deltaic lands built up by tidal accretions from the Gulf of Martaban and the Sittang estuary. The history of the formation of this plain is not one of uniform accretion, but rather of periods of growth interrupted by times of erosion with which the changes in the mouth of the Sittang river appear to have a close connection. This mouth, as referred to above, has moved from west to east and returned again several times in its history, eroding the lands on one side and depositing them on the other during its progress. It is inferred that 50 or 60 years ago the shore-line of the Gulf of Martaban was about 5 miles east of Ohne village, but to-day it is 20 miles east of Ohne. There has certainly been a very rapid growth of the land in this direction within living memory, and remarkable changes in the coastline are apparent from the various maps that exist.

The rapid growth of deltaic deposits of this kind implies a change of load and a fresh distribution of forces creating new strains in the earth's crust that cannot go on for ever without readjustment. There is reason to suspect the existence of at least one great fault below the alluvium and, so far as the Pegu earthquake is concerned, it is felt that there is some connection between the two.

**Pyu Earthquakes of 3rd and 4th December, 1930.**—The Pegu earthquake of 5th May, 1930, was followed by a series of great

shocks on 3rd and 4th December, 1930, the severest of which occurred about 1.20 a.m. on the 4th, and wrecked most of the masonry buildings in the town of Pyu, killing some 30 persons. Examination of the area by Dr. Coggin Brown and Mr. P. Leicester has led them to conclude that the epicentre of the Pyu quake lies a few miles to the west of that place, where the edge of the Pegu Yoma rises in a wall-like escarpment to a maximum height of over 1,700 feet above sea-level from the alluvial plains of the Sittang, which hereabouts average only some 140 feet above the sea. A local railway line crossing this tract was severely damaged, and exhibited twisting of rails and displacements of embankments similar to those caused by the Swa shock. In addition, cracks in the ground and sand-vents, the wrecking of a timber house and destruction of flimsy huts, which usually escape damage, again betoken a high degree of intensity.

A straight line joining the epicentres of the Swa and Pyu earthquakes, and continued to the south, passes approximately through the centre of the most disturbed area of the Pegu quake, follows more or less the outer boundary of the Pegu rocks of Oligo-Miocene age as mapped by Theobald,[1] and is at the same time approximately parallel to the main trend line of the Pegu Yoma. On the other side of the Sittang Valley the steep edge of the Karenni Hills and the Shan plateau rises, and it has long been held that the junction between the Tertiary and the crystalline rocks is marked by a great boundary fault. Whether movements of the outer boundary fault itself caused the earthquakes, or whether they are the result of the growth of associated smaller faults farther to the west, is not certain.

**The North-East Frontier (Htawgaw) Earthquakes.**—The frequency of earthquakes during recent years on the North-East (Chinese) frontier of Burma suggests that this forms part of an unstable land mass. The author had the opportunity of visiting this region between the second half of November 1929 and February 1930, and again between December 1930 and February 1931. Careful enquiries made by him among the local intelligent people and Government officials in the Htawgaw

[1] Theobald, W., "Geology of the Pegu Province of Burma," *Mem. Geol. Surv. Ind.*, vol. x, 1873.

subdivision elicited the information that at least two or three and sometimes more distinct earthquakes, besides slight tremors, occur there every year. In December 1928 these earthquakes attained devastating intensities, when they wrecked the strong granite masonry buildings at Htawgaw. On the 28th of December, 1928, at 5 and 6 a.m., severe earthquakes were again felt, which caused much damage to the stone masonry buildings at Htawgaw. The Assistant Superintendent at Htawgaw, reported that "on the 29th of December, 1928, between 7.20 p.m. and 6 a.m. the following morning we must have had no less than 30 to 35 shocks." The shocks continued at least at the rate of 3-4 a day, but another very severe one was felt at 6 p.m. on the 19th January, 1929. It was reported to be the severest shock ever felt in Htawgaw. All the stone masonry buildings at Htawgaw were so badly damaged that they were considered no longer fit for human habitation. This shock was reported by the Deputy Commissioners of Bhamo and Katha as felt in their districts also, and from at least as far east as Teng Yueh in Yunnan. From the nature of the damage done to the buildings, raised almost on solid rock, the writer concluded that the intensity of the shock on the Rossi-Forel scale must have been IX. Another very severe shock was experienced in the morning of the 4th June, 1929, and much damage was done by it. The exact extent of this seismic belt is difficult to delineate, since no careful records of the shocks were kept in the past. They appear, however, to be felt throughout the Myitkyina district, as a rule, and when particularly severe, are experienced even in the adjoining districts of Bhamo, Katha and the Upper Chindwin, and at least as far east as Teng Yueh in Yunnan. The Chinese Telegraph Master, at Teng Yueh, wrote in December 1929 that "earthquakes are felt here one or two times every day since October 1928." The plains of Wausawng seem to absorb the intensity of these shocks a great deal before they reach Myitkyina itself.

While the writer was at Htawgaw another very severe shock occurred on the 16th December, 1929, at 2.30 a.m., with an intensity of IX on the Rossi-Forel scale. Another severe one was felt on the same date at 9 a.m. As a consequence of these, cracks developed in various places, and landslips and

rockfalls occurred on the Htawgaw—Hkam Hkam road, which was blocked in several places as a result. The earthquakes continued all the time the writer was there, and are still occurring according to the monthly reports received from this area. It appears that during 1930 the earthquakes gained in intensity and frequency. They caused considerable damage between February and December 1930, the interval between the writer's two visits to this area. He did not see a single scar of a rockfall or a landslip in the hills opposite Langyang in February 1930, but in January 1931 the same hills were scarred with the traces of recent landslips and rockfalls. The earthquakes are generally preceded by earth sounds, which have been compared with "thundering of clouds," "bombardment of heavy guns," "rattling of trains," etc.

With regard to the causes of these earthquakes, the writer thinks that the junction between the granite and volcanic tuffs near the Lagwi Pass is faulted, and in his opinion it is movements on this fault that are responsible for these earthquakes. It is noteworthy that on either side of the fault the direction of the earth sounds becomes reversed. It was noted, while camping near the Lagwi Pass, that the sound did not seem to originate every time from the same spot, but rather that it appeared to travel, probably indicating movement at different places at different times along the fault line. The earthquakes near the Lagwi Pass along with the brontides were far more frequent and severer in intensity than elsewhere, and sometimes they appeared almost incessant. Occasionally while the writer was writing notes of one earthquake another would follow, and for the three nights during which he camped near the Lagwi Pass he had practically no sleep. The depth of the focus appears to be shallow, since the intensity dies away quite abruptly.

Sometimes independent minor shocks are felt in the Kamaing subdivision of the Myitkyina district, and these appear to have a seismic focus of their own. Some of the formations there are faulted, a fact further confirmed by the existence of a series of salt springs in them.[1] This view was amply confirmed by the severe earthquake of 28th January, 1931, which is described below. The same fact also seems to be true of the shocks

[1] *Rec. Geol. Surv. Ind.*, vol. lxvi, 1932, p. 39.

felt from time to time in the Wuntho subdivision of the Katha district.

**Kamaing Earthquake of 28th January, 1931.**—The main shock, which occurred at 2.35 a.m. (Burma Standard Time) and came suddenly and without fore-shocks, was very violent and lasted at least thirty seconds. From the nature of the damage done, the writer is convinced that the earthquake was of the first magnitude, and had an intensity of at least IX on the Rossi-Forel scale. Only the nature of the dwellings and the sparse population of the region prevented a great disaster. The principal shock threw the inhabitants of the epicentral area and its near neighbourhood from their beds. Even in Kamaing (25° 31′ 38″, 96° 43′ 5″), which is just outside the epicentral tract, all the glassware and crockery of the Inspection Bungalow were broken, three big almirahs were overturned, and mirrors and notice boards were thrown to the floor.

No masonry buildings exist in the epicentral area, but all those in Kamaing, the Court House, the Subdivisional Officer's bungalow and the P.W.D. Inspection Bungalow were severely damaged. Two small pagodas in the local *Pongyi Kyaung* (monastery) were destroyed. Even a small bamboo house in Kamaing collapsed. The bridge over the Indaw *Chaung*, which is 270 feet long and ten feet wide, had a general list downstream (33° S. of E.), and it sagged in the middle by about four feet. The second bridge in the 26th mile of the Mogaung-Kamaing road had its wing walls and abutments badly cracked, and it was subsequently dismantled and re-erected. In the Lawa tract of the Kamaing subdivision, which constitutes the epicentral area, even bamboo and wooden houses raised about 3 feet from the ground, which generally escape destruction by earthquakes, were completely wrecked.

The writer, during the course of his investigation, noted that big fissures, sometimes several hundred feet long, developed in the epicentral tract and its neighbourhood. These fissures in alluvial tracts were accompanied by spoutings of sand and water. The maximum thickness of such sand deposits in the neighbourhood of Kamaing was about 4 inches; the width was about 15 feet.

The epicentral tract is very hilly, and its average height above

sea-level is between 2,000–3,000 feet. Its maximum elevation is 4,982 feet above sea-level. The hill slopes were scarred in numerous places by big cracks, not infrequently about 2 feet wide and with a drop of about 3 to 4 feet on one side. Block fissures were also observed.

Numerous landslips and rockfalls had occurred in the epicentral tract. Not infrequently the fallen débris temporarily dammed the streams. This was noted by the writer in the Tanai Hka, Hkuma Hka and Hkada Hka, all of which had steep banks. The water in the wells in Kamaing remained dirty for 3 to 4 days after the main shock.

An earth sound was distinctly heard preceding the shock in the epicentral tract, and has been commonly compared to the "buzzing of a powerful motor car," to "distant thunder," the "screeching noise of a strong gale," etc.

The shock was felt over the whole of the Myitkyina district. Reports were received from as far north as Fort Hertz (Putao) and as far east as Htawgaw. It is not known how far it was felt in Yunnan. It was also reported from Maingkwan, the headquarters in the Hukawng Valley, where its intensity was reported to be severe and the duration of the main shock one minute. Southwards it was felt over the greater part of the Katha district, but not in the townships of Thabeitkyin and Pinlebu. The stationmasters of the Burma Railways from Myitkyina to Mawlu reported that the shock was distinctly felt. No reports, however, were received from the Bhamo and Upper Chindwin districts. The shock was reported to be fairly severe at Haungpa, which is situated on the boundary of the Myitkyina and the Upper Chindwin districts.

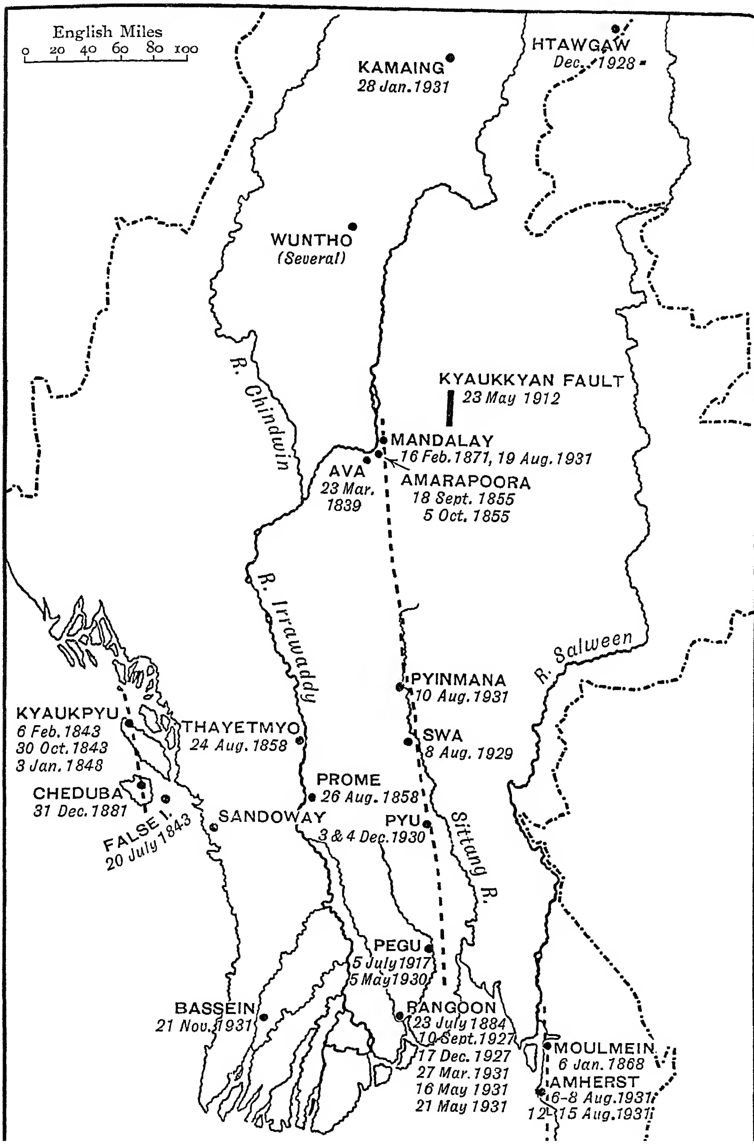
The writer concluded that movements along the fault between the Tertiaries and the crystalline schists and serpentines were responsible for the occurrence of the main shock and its after-shocks. The direction of the earth sound was reversed on either side of the fault. The after-shocks of this earthquake are still occurring.

It would appear from the foregoing that movement along the faults in the Shan plateau give rise to earthquakes, *e.g.* the earthquakes of May 1912. The Ava earthquakes of 1839 and 1858, the Amarapoora earthquakes of September and October

1855, the Mandalay earthquake of 16th February, 1871, the Pegu earthquakes of 5th July, 1917, and 5th May, 1930, the Pyu and Swa earthquakes of December 1930 (see Fig. 10), all seem to have occurred on the same fault line in the Central Belt, which probably marks the faulted junction of the crystalline rocks with the Tertiaries. It was noticed in the case of some of the Ava and Amarapoora earthquakes that the earth sounds distinctly came from the east. It is now well known that the edge of the Shan plateau forms an important boundary fault. Since the area is covered by an immense thickness of alluvium it is difficult to be positive, yet we know that in other parts this junction is a fault plane, *e.g.* in the Kamaing subdivision of the Myitkyina district, where, as shown above, movements along the junction of the Crystalline rocks and the Tertiaries were responsible for the severe earthquake of 28th January, 1931, and numerous after-shocks. The Akyab coast is again unstable, where, as shown in the sequel, recent changes of level have taken place. The Kyaukpyu earthquakes of 1843, 1848 and others have apparently occurred along this line (see Fig. 10). The North-Eastern frontier region of Burma, in the Myitkyina district, including parts of Yunnan, as shown above, also constitutes an unstable land mass cut by fissures which have not attained their final equilibrium yet.

**Volcanic quakes.**—Although most of the earthquakes Burma has experienced are of tectonic origin, the writer is of the opinion that earthquakes due to volcanic activity, though not of the same intensity as the tectonic shocks, must have disturbed Burma, especially in the Tertiary periods and later. It is apparent that the eruptions of the volcanoes of Popa, the Lower Chindwin, Wuntho, Kabwet, and Myaungmya district, must have violently shaken the surface of the country. But these earthquakes occurred too long ago to be recorded in history, though one instance, as mentioned by Bell,[1] is supported by tradition and legend : "According to tradition there was a great earthquake in 442 B.C., during which the great cone of Popa rose from the plains, but the native chronicles leave no record of how long it was active and when it became extinct."

[1] Bell, N. C., *The Iron and Steel Work in Burmah*, Government Printing Press, Rangoon, 1907.




G. 10.—Map showing epicentres of important earthquakes and general lines of weakness.

C.G.B.

## Alterations of Level.

The earthquakes we have just been discussing are connected, as we have seen, with the folding movements which give rise to the main mountain chains and hill ranges of Burma ; or, in other cases, with the faults and fractures which cut through the rocks of the country. In addition to these movements of folding and fracturing we find evidence also in parts of the country, especially round the sea coast, that some areas have recently been uplifted while other areas have been recently lowered or submerged. In places we find raised beaches, that is to say, beaches of rounded stones and pebbles formed by the waves of the sea, but now at some elevation above sea-level. In other places we find large flat areas which were once mangrove swamps, but which are now at considerable elevations above the sea.

These movements of elevation or subsidence have been studied only in a few parts of Burma, and the notes given below are in connection with certain examples, though there are doubtless many areas where these movements have taken place, but the results have not yet been recorded.

**The Arakan Coast.**—There is unmistakable evidence of recent upheaval in the Arakan Division, and this is believed to have alternated locally with periods of relative quiescence or submergence, which is always difficult to identify. According to Mallet, evidence of recent elevation is well observed in the Ramri group of islands off the coast of Arakan. The physiography of Ramri Island (see Plate VI, Fig. 2) is itself a proof of upheaval. The southern portion of Round Island is occupied by a little rocky tableland 100–150 feet high, and the remainder by a plain elevated but a few feet above the sea. A portion of the plain is composed of rounded pebbles and boulders of rocks, lumps of coral, sand and broken shell, undoubtedly representing a raised sea beach. The rest is an alluvial flat, formerly a mangrove swamp, but now occupied by paddy fields, strewn with large rocks to which marine shells still adhere.

At the northern end of the island there is on the beach a detached rock which affords striking evidence of the recent upheaval of the coast, as it is crowned by an aggregated mass

of marine shells, the base of which is about 6 feet above the present high-tide level, and the upper surface of which is covered with vegetation. Evidence of the same nature is forthcoming on Flat Island to the south. A map of the latter that accompanies Captain Halsted's paper shows the present island to consist of three terraces differing from each other in level by 6 or 8 feet, showing that the island underwent elevation three times. It is believed that the main movements took place about the middle of the seventeenth century, while the last phase occurred about the year 1750, when it was accompanied by a very violent earthquake.

The measurements by Captain Halsted show the total elevation to have been 9 feet at Foul Island (50 miles south-east of Cheduba), from 12 to 22 feet in various parts of Cheduba itself, and 13 feet at the Terribles, west of Kyaukpyu. On the western coast of Ramri Island there is a raised beach about 20 feet above the sea, strewn with lumps of coral and rocks bored by marine organisms whose shells still remain in the holes.

These changes in the elevation of the Arakan coast, stated to extend over more than 100 miles, were attributed by Captain Halsted to the severe earthquake of 1762. Men were living at the time of Captain Halsted's visit in 1841 who had fished over the then dry land. But the evidence was considered by Mallet to be extremely vague, and the attribution of the changes to the earthquake is entirely a matter of assumption.

On the other hand, as Theobald remarked, the archipelagic character of the present Arakan coast and the presence of drowned valleys suggests subsidence, and in the case of the west coast of Ramri it seems very probable that such a movement preceded the upheaval. The submarine ridge between Baronga Islands and Cheduba suggests subsidence at some period.

**The Andaman and Nicobar Islands.**—Evidence of recent uplift of the land was observed by Messrs. Tipper and Gee in some of the islands of the Andaman group. Kurz was of the opinion that these islands had lately subsided, since certain trees were observed at sea-level which normally only grow in high forest. Tipper, however, thought that this might equally well be due to a landslip, since the structure of the islands is such that slips of some size could easily take place.

The coast of the two small islands, the Twins, to the west of Rutland Island, furnishes unmistakable evidence of recent rising of the land; since there is a sandy beach about 6 feet above high-tide level, and a recent pebble conglomerate similarly raised above the present high-tide level.

On the west coast of the southern island of the Cinque Island group is a raised beach of fine sand with recent shell fragments about 15 feet above high-water level. Similarly, a raised coral beach at the south end of the Henry Lawrence Island, Ritchie's Archipelago, is shown in Plate VII, Fig. 1. In Little Andaman Island similar evidence is observed, A definite platform, evidently the result of coastal erosion, now situated above the eroded coast level, together with a small cave in the sandstones well above the present high-tide mark, bear evidence of recent elevation. At the south-west corner of Hut Bay unquestionable evidence of the occurrence of beds of recent coral rock *in situ* above the present sea-level has been recorded. A short distance inland a small stream enters from the west. In the bed of this stream boulders of recent coral were abundant, and were also found in the dense undergrowth nearby. Exactly similar evidence was recorded in some of the islands of the Nicobar group.

What has been said tends to prove definitely that the Arakan coast and its continuation southwards in the Andaman and Nicobar Islands have been lately affected by earth movements, resulting in the relative uplift of land.

**The Delta of the Irrawaddy.**—Theobald was of opinion that the Irrawaddy delta showed signs of elevation from the following evidence: (1) the number of small lakes throughout the delta; (2) the comparative narrowness of the river channel between its permanent banks; (3) the presence of raised banks of coral near Gwa on the coast, and of shelly sand and shells of living species below the surface in the plains, at some distance from the coast. Theobald noticed that the deltaic deposits dip seaward or to the south at a greater angle than the surface of the land, which proves that the process of elevation has been greater inland than towards the Gulf of Martaban. This is quite in accordance with evidence of an increased elevatory movement as we proceed up the coast northwards.

**South Tenasserim Coast.**—The Tenasserim coast affords indubitable proof of subsidence. The present shore-line is very ill-defined, there being often more than a mile's distance between high and low tide. The evidence of comparatively recent depression of land, as recorded by Coggin Brown and Heron, is found in the Heinze Basin, a narrow-mouthed bay, the greatest length from north to south being 18 miles, and the greatest breadth about 6 miles. Much of it is mangrove swamp, with branching tidal channels of unexpected depth. The maximum depth is 13 fathoms, just inside the entrance to the basin, and channels of 5 fathoms extend for some miles parallel to the longer axis of the bay; a depth of 5 fathoms is not met with in the adjacent sea for 6 miles outside the entrance, and the basin is thus an area considerably below the level of the adjacent sea bottom. The disturbance of alluvial tin-bearing deposits in the adjoining mine of Kanbauk, and the great depth to which they extend below sea-level are facts which prove that this neighbourhood has subsided comparatively. Morrow Campbell also states that other tin workings along the Tenasserim river have exposed, a few feet above present high-tide level, two layers, several feet apart, of big tree trunks in their natural position, buried in silt below the present forest level. Above all, the form of the irregular coastline is that associated with the subsidence of land and its subsequent overflooding by the sea.

In conclusion, it may not be rash to assume that the coasts of Burma in late geological times, as seen in the Arakan and Tenasserim Divisions, underwent submergence, and that this was followed by upheaval, as noticed so well in the Irrawaddy delta and the Arakan coast.

An account of the volcanoes of Burma will be found in the chapters on Igneous Activity in the sequel.

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# CHAPTER V

## HOT SPRINGS

Hot springs are usually associated with the later stages of volcanic activity, and just as volcanic phenomena are manifested particularly along fissures or faults in the rocks of the earth's crust, so hot springs often tend to be associated with similar faults. Hot springs occur all over Burma and in many parts of the Shan States (see Fig. 11). In some places the temperature of the water is very high, reaching 10° or 12° below boiling point, and in a few cases actually touching boiling point. Generally these springs occur in beds of streams; the water in almost all cases is perfectly clear with a beautiful blue tinge. The pools are filled with grey mud, and no distinct openings are visible on the surface, though bubbles of steam rise continually from the bottom, and there is frequently a strong smell of sulphuretted hydrogen. The water is usually highly charged with salts, the principal ones being the sulphates of lime and magnesia with traces of alkalies, chiefly potash. Many of these springs would be highly beneficial in the case of chronic rheumatism and gout.

**The Shan States.**—The Shan Plateau, as mentioned elsewhere, is traversed by a series of parallel faults, which give rise to scarps and cliffs, and along some of these fault lines are found hot or brackish springs, such as the well-known examples in the Nam-tu at Hsipaw, near Pengwai and several between Nakang and Loimauk, while a very important one exists at Namôn. It may be mentioned that some of the faults do not reveal their presence by a visible scarp. Thus the fissure on which the great hot spring of Lashio is situated does not form a scarp, and can only be detected by the presence of such phenomena as the springs along its course. This fault was in

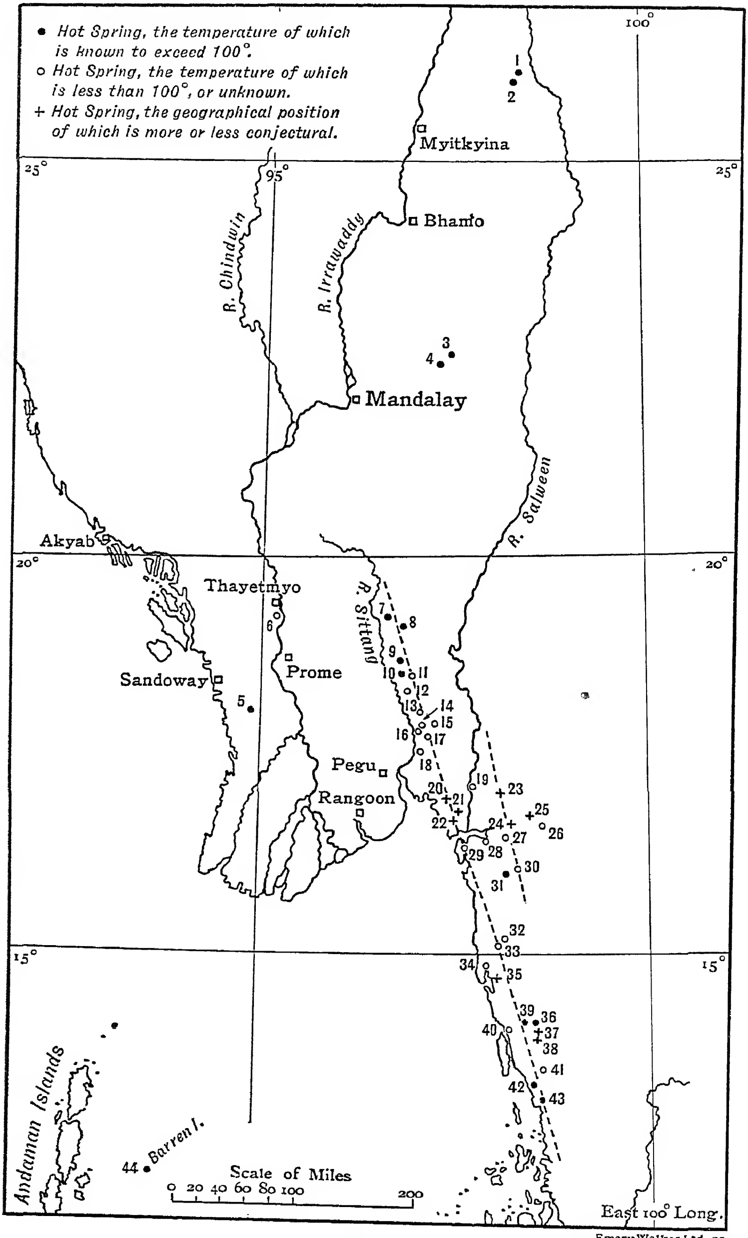
• Hot Spring, the temperature of which is known to exceed 100°.
○ Hot Spring, the temperature of which is less than 100°, or unknown.
+ Hot Spring, the geographical position of which is more or less conjectural.
Myitkyina
Bhamo
R. Chindwin
R. Irrawaddy
Mandalay
R. Salween
Akyab
Thayetmyo
R. Sittang
Prome
Sandoway
Pegu
Rangoon
Andaman Islands
Barren I.
Scale of Miles
0 20 40 60 80 100 200
East 100° Long.
25°
20°
15°
95°
100°
Emery Walker Ltd. sc.

FIG. 11.

## DISTRIBUTION OF THE HOT SPRINGS IN BURMA

1. Munglang Hka (25° 58′, 98° 29′).
2. Yinchingpa (25° 56′, 98° 23′).
3. Pengwai, Northern Shan States.
4. Namôn, Northern Shan States.
5. Sandoway river (18° 6′, 94° 54′).
6. Bule (19° 15′, 95° 16′).
7. Lepanbewchaung (19° 16′, 96° 36′).
8. Kayenchaung (19° 10′, 96° 36′).
9. Chaungna-nay (18° 44′, 96° 46′).
10. Kayloo Myoung (15° 33″, 96° 51′).
11. Bin-byai (18° 33′, 96° 55′).
12. Mai-Pouk (18° 19′, 96° 54′).
13. Sair-O-Khan (97° 4′, 18° 4′).
14. Hteepahtoh (17° 56′, 97° 3′).
15. Vadai Chaung (17° 56′, 97° 12′).
16. Koon-Pai (17° 55′, 97° 1′).
17. Maiting (17° 53′, 97° 4′).
18. Kyoung Chaung (17° 35′, 97° 2′).
19. Gyo (17° 10′, 97° 39′).
20. Nga Yai Kyoon Juin, in Martaban.
21. Seinli, in Martaban.
22. Kaline Aung, in Martaban.
23. Poung Yaboo, in the District of Salwen.
24. Noungtyne.
25. Mai-Palai.
26. Mya-waddi (16° 43′, 98° 32′).
27. Poung (16° 9′, 98° 14′).
28. Yebu (16° 34′, 98° 9′).
29. Damathat (16° 33′, 97° 52′).
30. Bonet (16° 27′, 97° 37′).
31. Ataran (16° 6′, 98° 2′).
32. Myan-Khoung (15° 13′, 98° 7′).
33. Thalan-Khoung (15° 10′, 98° 3′).
34. Nat Gyi Zin (14° 55′, 98° 0′).
35. Henzai.
36. Myitha (14° 13′, 98° 33′).
37. Paltha Kyoung.
38. Mandoo.
39. Kaukyen (14° 12′, 98° 25′).
40. Moung Mayan (14° 9′, 98° 9′).
41. Toungbyouk (13° 33′, 98° 40′).
42. Pai (13° 26′, 98° 33′).
43. Palouk (13° 13′, 98° 40′).
44. Barren Island (12° 11′, 93° 54′).

The spellings and coordinates as mentioned by Oldham are given.

existence before the deposition of the Tertiary silts of the Lashio coalfield, for they pass across it without any trace of disturbance of one side or the other.

**Karenni.**—A hot spring (19° 10′, 96° 35′) occurs near Kayen-chaung. It rises in the bed of a small stream, so its temperature has not been measured. A hot spring (18° 44′, 96° 46′) with a temperature of 108° F. rises in the Choung-ma-nay valley, between the Choung-ma-nay and Youk-thwah streams. The spring forms a pool of tepid water, and rises through cracks in a hard rusty sandstone.

A very hot spring exists in the bed of the Hlayloo-myoung Chaung in lat. 18° 33′ N. and long. 96° 51′ E. It forces its way to the surface at several spots, through a bed of coarse granitic sand which conceals the actual point of issue. A number of hot springs have been recorded from the Shwegyin district, but no other details are available.

**Tenasserim.**—There are several hot springs in Tenasserim. Near the town of Moulmein in the Amherst district are the hot springs of Ataran, situated near the old town of the same name. Dr. Helfer described them thus: "There are ten hot springs or hot water ponds, of which I could only examine the nearest, as the access to others was through deep water of 130° F. This was a semicircular pond of about 50 feet in circumference. In one place it was 35 feet deep. The spring was in a state of active ebullition and much steam arose from its surface. A large quantity of carbonic acid was evolved. The ground round the spring is strongly impregnated with iron, and the water which runs over the ochre mud has a strong styptic taste." The springs on the Attaran resemble the celebrated water of Toeplitz in their composition.

Hot springs also occur about 4 miles below Myitha and a few miles north of the latitude of Tavoy. The water is highly charged with sulphuretted hydrogen. The temperature is about 119° F.

**Pai.**—On the margin of the granite range at Pai, east of Tavoy, there is a series of hot springs. They occur more or less on a line and are uniformly of a saline character and are probably situated on an important fault line. The principal spring is in a little sandy basin enclosed by granite rocks on

the margin of a cold water stream. Water bubbles up from three or four vents, and the temperature is about 198° F., 14° below boiling point. It is noteworthy that this spring is not situated in a valley, but on the side of a hill about 1,000 feet above sea-level.

According to J. F. Stevenson, the most striking feature is the jet of steam which issues with considerable force and forms an immense cloud overhead. The water which pours from the hole with the steam, or which comes in contact with it, is hot enough to boil an egg in three minutes. Stevenson, who with others visited the spring, remarked that " all the rocks (granite) about the hot water are hot : and the ground on which we slept, about 30 yards from the stream and several feet higher than it, became very hot under our beds at night. We removed some stones and found the ground hot beneath them. We dug a hole near our beds, and steam began to rise from it at eight or nine inches from the surface of the ground. Two of our party heard a rumbling sound several times during the night, which may have been thunder, but which appeared to us to be subterranean." On analysis the water was found to contain iron, alumina, lime, potash, soda, silica, hydrochloric acid, sulphuric acid, hydro-sulphuric and nitrogenous organic matter.

**Palauk.**—Major McLeod investigated the group of springs at Palauk. There are two spots where the springs show themselves, one immediately on the bank of the river and the second two or three minutes' walk inland. There must be 30 or 40 small springs bubbling up over an area of about 50 feet by 20 feet. There are other springs about 10 or 12 miles in a N.N.W. direction from these, at a place called Pè.

**The Central Belt.**—Hot springs are not so common in the Central Belt of Burma as in the Shan States or the Tenasserim Division. A hot spring recorded by Theobald occurs in the bed of the Bulay stream, in lat. 19° 15′ N. and long. 95° 16′ E. As this spring appears in the bed of a stream its proper temperature cannot be determined.

**Shwebo District.**—Hot springs occur in the Shwebo district at Halin, a name given collectively to the group of villages of Yebugonyat, Twinmayat, etc. (22° 27′, 95° 49′). Hot water

issues here in a number of places in a north-south direction over a distance of 150 yards. Where the discharge of water is more copious, enclosures of earth lined with wooden planks have been built to collect the water in shallow pools or baths, with an outlet on one side. The temperature of the water of these baths varies from 53° to 73·5° C. In the southernmost bath, the temperature of which is about 64° C., hydrogen sulphide bubbles intermittently or continuously in several places. The following is the analysis of water as given by Captain Walker :

| | |
|---|---|
| Sodium Chloride - - - | 0·68 |
| Magnesium Chloride - - | 0·02 |
| Calcium Chloride - - - | 0·09 |
| Calcium Sulphate - - - | 0·01 |
| Water - - - - - - | 99·20 |
| | 100·00 |

**Myitkyina District.**—A hot spring (25° 56′, 98° 23′) was visited by the writer a little south of the Lashi village of Yinchyingpa, Htawgaw subdivision, Myitkyina district. Blocks of silicified tuff are seen scattered over the granite forming the country rock. The hot water gushes out with some force from the main crevice about 10 inches wide, and steam escapes copiously. Besides, there are seven subsidiary holes where hot water issues with some steam. A little above the hot water spring, a brackish water spring occurs.

Another hot spring (25° 58′, 98° 29′) was found by the writer on the right bank of the Munglang Hka. A fairly copious discharge of tasteless hot water comes from underneath the granite boulders in a number of places. A sulphurous smell was noted, and steam was seen issuing from a number of places. A reddish deposit of ferric oxide occurs nearby, while some boulders in the neighbourhood are coated black with ferrous sulphate. A stick about 3 feet long could be thrust into the fissure from which the water was rising. A sill of andesite in the neighbourhood of the spring and some more farther upstream were examined by the author.

**The Arakan Coast.**—On the Arakan coast a few hot springs occur ; one has been recorded close to the headwaters of the

Sandoway river in the approximate position of lat. 18° 6′ N. and long. 94° 54′ E. It issues with some force from a vertical fissure in a slaty rock; water flows from it at the rate of about $1\frac{1}{2}$ gallons a minute at a temperature of 110° F. Sulphuretted hydrogen and carbonic acid gas are present.

**Barren Island.**—A hot spring exists on the beach of Barren Island at the landing place. The shore between the cliffs of ancient lava and the recent stream has a length of about 40 yards, and along it the hot water issues in numerous places from between the shingle. The level of the springs rises and falls with the tide, and according to Mallet the high temperature of the water is due to the recent lava and the scoriaceous and other porous material beneath it not having yet completely cooled. The temperature of the spring is 130° F. and is gradually falling, as is to be expected, owing to the gradual cooling of the lava.

In conclusion, it would appear from a reference to Fig. 11 that the majority of hot springs numbered 3–27 are situated on an important fault line running in a N.N.W.–S.S.E. direction, and the position of the springs 3–15 seems to coincide almost with the outer limits of the massif of the Shan plateau and its southern continuation. It would not be entirely hypothetical to assume that they either lie on the main boundary fault itself, separating the Shan plateau from the Tertiary region on the west, or on one situated a little to the west of it. As mentioned above, it is not improbable that the movements responsible for some of the recent earthquakes in Burma may have occurred along this line. So far the occurrence of springs indicates that this line extends for about 300 miles. Further, it appears that the hot springs 28–31 lie on another, though smaller fault, to the east.

An account of salt springs will be found under "Salt" in the sequel.

**Freshwater Springs.**—Apart from these hot and brackish springs there are numerous fresh-water springs in different parts of Burma. Such springs may issue from porous rocks underlain by impervious strata. This is admirably illustrated by springs observed by the writer in the Mergui district, where at low tide copious supplies of water are seen flowing from

numerous springs where porous sandstones and quartzites are underlain by impervious shales. A spring may also appear where highly jointed and fissured strata lie in a rainy locality. The water sinks into the crevices, until its further passage is blocked, when it appears above ground. Such springs are common in igneous rocks, and examples are very numerous. The gneissic hills east of the Sittang give rise to a number of freshwater springs, which are also common round Mount Popa, where they supply cool fresh water to the neighbouring villages.

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PLATE VII.

FIG. 1.—A RAISED CORAL BEACH AT THE SOUTH END OF HENRY LAWRENCE ISLAND, RITCHIE'S ARCHIPELAGO.

FIG. 2.—MUD VOLCANOES, MINBU.

# CHAPTER VI

## MUD VOLCANOES

It should be clearly understood that the " mud volcanoes " of Burma have nothing whatever to do with true volcanic phenomena, and that the name " volcanoes " is rather a misnomer. It is now definitely established that they owe their origin to the escaping gas associated with petroliferous strata. The east coast of the Bay of Bengal and the islands fringing it from Chittagong to Cape Negrais have from time immemorial been affected by such outbursts. This belt of disturbance can be traced by occasional submarine outbursts still farther southwards past the Andaman and Nicobar Islands and beyond. There is every gradation between a small insignificant oil or gas seepage and the conspicuous mounds or cones like those on the Arakan coast, where terrific outbursts have been mistaken for volcanic disturbances.

**Two Geographical Groups.**—The mud volcanoes of Burma can be arranged in two groups according to their geographical distribution, namely, those situated along the eastern and western borders of the Arakan Yoma respectively. The eastern group contains the mud volcanoes of the Minbu, Prome and Henzada districts. Similar mud volcanoes, which have never been described, occur associated with oil seepages in the Lower Chindwin district. Those on the western flanks of the Arakan Yoma, however, especially in the Ramri group, hold the first place in magnitude and in the violence of their paroxysmal eruptions. Theobald has mentioned two mud volcanoes occurring on the coast not far from Cape Negrais. Those of Minbu (see Plate VII, Fig. 2) have been described in great detail by Noetling, and are situated a little over half a

mile west of the town. There are three groups of them, of which the southernmost is the most important.

Mud springs occur east of Kin-u in the Shwebo district in clusters of two to six little pseudo-craterlets with diameters varying from 2 to 8 feet. According to Sir Edwin Pascoe [1] fine slushy mud that oozes out from the top builds low crater-like mounds, while the accompanying water leaves on evaporation a white crust of alkali salts on the neighbouring surface. Similar springs occur farther south and east of Kyigan (22° 42′, 95° 39′), west of Kokkan (22° 40′, 95° 42′) and east of Thakkutaw near Wetlet (22° 32′, 95° 47′). It is remarkable that although these springs occur in groups in every locality, the different localities lie approximately on a line of weakness joining the Kin-u—Thakkutaw groups.

**Two Types : Basins and Cones.**—Two types of mud volcanoes can be recognised by their shape, *i.e.* basins and cones, though sometimes it is very difficult to distinguish one from the other. The *basins* are more or less circular or elliptical holes in the ground. When active they are filled with muddy water, and the incessant escape of small gas bubbles gives the liquid the appearance of boiling, and also produces gurgling noises. Some of these vents are permanent, while others are only temporary, the vent becoming clogged. Fresh gas bubbles then begin to rise at another place. Petroleum is occasionally brought up with the gas, and may form a more or less continuous film on the surface of the water. The *cones* are built up of mud ejected from the vent, and commonly possess steep sides with a crater in the centre (see Plate VIII, Fig. 1), sometimes with a diameter of several feet. The conditions favourable to the formation of a cone seem to be the presence of a great mass of viscous mud combined with a certain amount of gas pressure. In this case the mud is ejected in flakes, which are thrown up high in the air and fall back with a splashing noise around the vent. If the action goes on for some time a cone is raised. The maximum height attained by a cone at Minbu is between 40 and 50 feet, though, being composed of soft mud, it is soon lowered by the action of rain. It is interesting to note that

[1] *Rec. Geol. Surv. Ind.*, vol. lxii, 1930, p. 103; and *ibid*, vol. lxv, 1931, p. 93.

FIG. 1.—CRATER OF A MUD VOLCANO, MINBU.

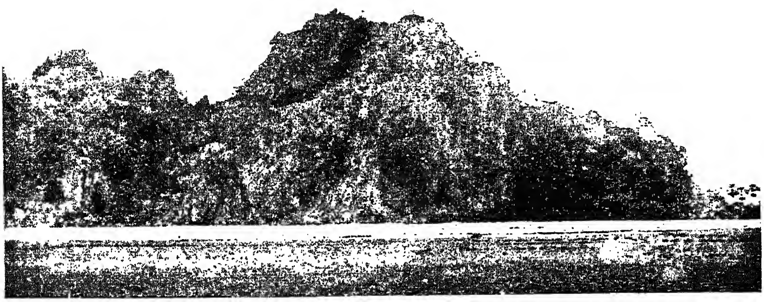

FIG. 2.—NORTHERN PART OF THE LIMESTONE HILLS, NEAR KAYON.

common. At the top of a conical hillock is a crater, filled with liquid or viscid mud through which the gas escapes. The surface of some of these mounds, especially on the Ramri islands, is composed of angular fragments of rock which have been thrown out along with the mud. The size of the mounds in Ramri Island varies from 50 to 100 yards in diameter, with a height of 15 to 20 feet, though exceptionally large ones, as the two near Pagoda Hill in Cheduba Island, attain a diameter of 200 to 250 yards, varying from 100 to 1,000 feet above sea-level. These vents are indeed much larger in point of size and activity than those of Minbu. Their eruptions produce, besides gas (mainly marsh gas with other petroleum hydrocarbons) and mud, a small quantity of petroleum, as well as saline matter which principally consists of common salt with sodium and calcium sulphates. The angular fragments of rock which are ejected during the paroxysmal eruptions vary from half an inch or less to 4 or 6 inches in diameter, while stones of half a cubic foot and more are uncommon. The great majority of these stones consists of shale and sandstone, which constitute the rocks of the neighbourhood.

**Quiet and Paroxysmal Eruptions.**—The mud volcanoes of Burma are of two types. The first is the commoner, quiet type, in which blue mud is brought up to the surface by the escaping gas. This mud represents the disintegrated material of the underlying strata. The second type is the paroxysmal or violent type, where the ejected material, including broken fragments of rock, is thrown sometimes to a great height with tremendous force. The action here is similar to that of a geyser eruption, where the accumulation of energy below is sufficient to overcome the pressure of the material choking up the vent. In this case, as suggested by Sir Edwin Pascoe, clogging of the vent is probably due to the greater hardness and smaller porosity of the strata. " The slowly percolating gas gradually accumulates below the fissure, which is blocked with material left there by the last outburst, until the pressure is sufficient to lift this and fling it and other broken pieces of rock out at the aperture, accompanied by saline mud. The violence of the outbursts varies with the length of the interval between them, and both are probably dependent on the resisting power of the blocking

material. The pressure sometimes must be enormous. Rumbling noises are heard and the friction between the fragments is sufficient to ignite the gas."

**Fiery Eruptions.**—Sometimes these eruptions are fiery, and in one on the island of Cheduba the flames rose to a height of a thousand feet whilst the circumference was five hundred feet. These flames light up the country for miles around and are visible far out to sea. As Mallet believed, they are due to the ignition of gas, caused by the friction between the rock fragments, and the consequent production of sparks. The eruption of the Cheduba volcano, which took place on the 21st of January, 1904, and lasted 45 minutes, is reported by eye-witnesses to have been the longest and most violent ever known. An eruption in July of the previous year was the only one during the preceding 10 years.

**Submarine Eruptions.**—If the eruption is submarine the accumulation of stones and mud sometimes forms islands or shoals, which, however, are soon washed away by the waves. The sea off the coast of Arakan is more than usually shallow. For purposes of illustration a brief summary of the formation of a new island on 15th December, 1906, off the north-west corner of Cheduba Island on the Arakan coast of Burma is given here. The island was 307 yards in its greatest length, running N.N.E.–S.S.W. and 217 yards in breadth in a north-west—south-easterly direction. Its maximum height, above high-water mark, was 19 feet, and it was entirely composed of greyish brown mud of a clayey nature with a small quantity of stones. Before the appearance of land, loud rumblings and rushing noises were heard, and the sea was in a much disturbed state.

There was no activity visible in the island on the 30th December, except at the northern end, where several small craters, varying in size from one to six feet in diameter, were still exuding mud,. but only in small quantities and not with any great violence. The result of several observations gave a mean temperature on the major portion of the island of, at two feet below the surface, 96° F., and three feet below, 104° F.: whereas at the summit the temperature one foot below the surface, was 104° F.; two feet below, 108° F.; three feet below, 138° F.;

and three feet six inches below, 148° F. The whole island gave out a strong smell of sulphur, which was almost overpowering close to the holes bored for taking the temperature. The island rose gradually from a depth of 11 fathoms, the diameter at the base being a little over half a mile.

This island is part of a chain of mud volcanoes which appear along the eastern side of Cheduba Island and the islands immediately south of it. This line continues again for some 50 miles farther to the north. The formation of new islands has also been observed in the Caspian Sea in connection with eruptions of the mud volcanoes of the Baku district.

**Connection of Paroxysmal Eruptions with Seismic Activity.**—Dr. Coggin Brown has discussed Mallet's theory that there is an intimate connection between the Ramri mud volcanoes and seismic disturbances, for some of the eruptions have coincided with, or followed immediately upon, the occurrence of important earthquakes. As the arrangement of the mud volcanoes shows that they must be aligned upon some line of weakness in the strata, it may be supposed that the effect of such a sudden shock on an unstable system must be either to loosen the superimposed strata and allow the pent-up gas to escape; or to close the fissure from which it was already escaping, and so develop sufficient pressure to rupture the strata with explosive violence. Out of the few eruptions of which accounts have been published, three certainly, and probably four, were synchronous with earthquakes. During the principal shocks of the violent earthquake on 26th August, 1833, Dr. McClelland states that flames rose to a height of several hundred feet from one of the Kyaukpyu mud volcanoes. A similar occurrence took place during the earthquake of 23rd March, 1839. The submarine outburst near False Island on 20th July, 1843, was immediately preceded by a like disturbance. During the great earthquake of 2nd April, 1762, two volcanoes are said to have been opened in the Chittagong district. Similar evidence was recorded by Colonel Sladen regarding the earthquake shock of 31st December, 1881. The observer was at a distance of 33 miles from the scene of eruption in the island of Cheduba, and from that distance the flames appeared at times to reach halfway up from the horizon to the sky, and to have a lateral

breadth of 30 to 40 feet. They continued to issue forth for about 15 minutes, and then suddenly disappeared.

**Greater Activity during Rains.**—Several observers confirm the fact that the mud volcanoes are more active during the rains. This may be due to the accumulation of water beneath, which exerts great pressure on the gas. This is also true in Java and the vents near the mouth of the Sea of Azov. Noetling also remarked that the Minbu vents appeared to him more active during the rains, or rather at high water, and suggested that the rise of the river was the cause.

**Temperature of Mud Volcanoes.**—As remarked by Mallet, the temperature below the surface is not high, as evidenced by the ejection of lignite and pyrites from the Arakan vents; there is usually a difference of only a few degrees between the temperature of the mud and the air. This slight excess of temperature, in spite of the evaporating action of the bubbling gas, may be due to the depth from which the mud is derived, to the churning action of the gas, and to surface heat. The highest temperature recorded by Noetling is 97° F., but in general it is seldom higher than 85° F., while the majority of the vents show a temperature between 75° and 82° F. In other words, the temperature is much lower than that recorded in any of the pit wells in the Yenangyaung oilfield. It is therefore beyond doubt that the source of the mud must be close to the surface.

**Origin of Mud Volcanoes.**—It has already been mentioned above that the mud volcanoes are simply extrusions of mud, etc., brought about by pressure of the lighter petroleum hydrocarbons along some line of weakness in the strata. Owing to faulting or accidental fissuring the pressure is relieved, and the gases breaking through the remaining superimposed strata form a mud volcano. In other oilfields, where these "volcanoes" do not exist, the pressure is either not strong enough to force gas, water and oil through the shale or clay bands, or else the pressure has been gradually relieved through the existing fissures. However, some of the severer paroxysmal disturbances experienced along various parts of the coast, as noted above, are connected with true seismic phenomena.

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## CHAPTER VII

### DENUDATION

As Burma is situated mainly in the tropics the most important weathering agents are rain and running water, aided to a very considerable extent by the heat of the sun. By far the greatest amount of denudation of the country is brought about by the action of rivers.

**The Action of Rivers.**—Burma experiences a monsoon rainfall; in other words, practically the whole of the rainfall, which in most areas is heavy, falls between the months of May and October. The rivers rise quickly soon after the advent of the rains, and they bring about a considerably greater erosion during the rainy season than they could normally accomplish in a number of years if their volume was practically constant. It has already been shown that the Irrawaddy is one of the fastest eroding of the large streams of the world, and removes one foot of rock from the whole of the drainage area of its basin in about 400 years. Besides the main rivers of Burma there are numerous mountain torrents which flow through the hills and during the monsoon period remove a not insignificant amount of sediment.

**Action of Rain.**—Rain should, perhaps, be taken before the action of rivers; but in point of view of its importance as a denuding agent it is at least second to the action of running water. Rain works in two ways, mechanically and chemically. In Burma the torrential showers of the rainy season, which occur over the greater part of its area, wash away loose material and carry it into the nearest streams. Thus it is the rain which, by its mechanical action, first loosens a large quantity of the sediments which ultimately find their way into the big rivers and so are carried to the delta or to the sea. So important is

this mechanical action of rain in the wetter parts of Burma that great care has to be taken in clearing hillsides of vegetation. For as soon as the vegetation, particularly the forest covering, is removed, the soil is exposed to this denuding action of rain. In Arakan and other regions considerable areas of what has been *taungya*[1] have now been swept bare of soil by rain.

Chemically, rainwater charged with carbonic acid gas is able to dissolve many different kinds of rock, especially limestone. In Burma a limestone formation extends right from Mergui in the south to beyond the northern borders of the Shan States. The great sheet of limestone has been dissolved or otherwise removed in places so that, especially in the south, only isolated hills now remain. These percolating waters remove therefore enormous quantities of limestone from the Shan plateau and adjoining regions. Beautiful caves, which are described separately in a later chapter, have been carved out as a result of the dissolution of the rock along well-marked joint planes. However, in the Shan States there are no open caverns in the great bulk of the limestone, owing to its universally shattered condition, which causes the mass to settle down as underground solution proceeds; though in the superjacent, more compact, Permo-Carboniferous limestone caverns are common enough. Thus the carbonate of lime which would ordinarily be deposited on the walls of caverns and fissures is in this region brought to the surface and thrown down in the open. The brecciated structure of the limestone also allows water to percolate freely through the mass in all directions, and this no doubt adds to the rapidity with which it is dissolved.

In the Dry Zone of Burma the action of rain is particularly important. This area lies in the middle of the central belt of the country, and constitutes the major portions of the districts of Mandalay, Sagaing, Shwebo, Pakokku, Myingyan, Meiktila, Magwe, etc. The chief feature of the Dry Zone, as its name indicates, is its very low rainfall, with an average of 20–30 inches a year. This amount, though small, falls in a few torrential showers. The amount is insufficient for the growth of a good vegetation cover, and so the soft sand-rock and clays of

[1] Shifting patches of hill cultivation.

the Dry Belt are exposed to the full force of the rain. Furthermore, the rocks are so easily susceptible to the action of rain and running water that they have been carved out into a topography similar to the "Bad Lands" of Nebraska or to parts of California, with branching tortuous and deep-cut water-courses, and the easiest road from one place to another is more often than not twice or thrice the direct distance. Owing to its soft and homogeneous nature the sand-rock, when capped by hard boulders or small blocks of sandstone, weathers into earth-pillars. A similar feature is sometimes observed in the rainier parts, where small bushes and trees, with stones collected around their bases, stand upon slightly elevated mounds or cones of sand. In cliffs the sand-rock is easily subject to landslips, but weathers into compound buttresses as seen in Plate XII, Fig. 1.

**Action of the Sun or Insolation.**—As Burma is mainly situated in the Tropics the action of the sun is very strong, especially in the Dry Zone, where the difference between the day and night temperatures is considerable. As a result of the consequent repeated unequal expansions and contractions the rocks crumble to powder and form sand. The material which has been rendered loose and incoherent is then carried away by running water or wind.

**Action of the Wind.**—In Burma the action of the wind is particularly marked in the Dry Belt. Frequently in the hot season whirlwinds occur, rushing across the country with a noise like that of an express train. Sand and dust particles are picked up by the wind and blown to considerable distances. During the journey the particles are rubbed one against the other and worn down and polished. In addition, the sharp particles of sand, being blown against rock surfaces, wear and polish them.

**Action of Frost.**—Frost also plays its part in some regions, especially in the mountainous tracts of Burma, *e.g.* the Shan Plateau and the Northern Hill Ranges, where the temperature at night is low enough for water to freeze. As a result of this the mountains of Burma are undergoing very active denudation. As they are all young fold mountains, their erosion proceeds at a very rapid rate. The deltas of the Irrawaddy

and the Sittang give an idea of the amount of silt that must have been worn down from the hill ranges of Burma in the comparatively short interval that has elapsed since their elevation towards the close of the Tertiary period. Landslips and landslides of great magnitude are not uncommon in these hilly regions. Fortunately the dense forests and thick undergrowth form a protective covering, otherwise the destruction would have been still more severe.

**Action of the Sea.**—On the Arakan and Tenasserim coast the sea wears away the land by the action of the waves, tides and currents. During the monsoon period the gales are particularly strong, and lash the waters of the Bay of Bengal into great fury, producing huge waves. On approaching the coast the waves attain great heights, and by their impact and constant beating they batter down the rocks. As a result of this a jumbled series of angular and subangular boulders is visible between tide levels on headlands, especially when they are composed of granite or similar hard rock. Similarly, the hard rocks are left as headlands, and bays are carved out from soft rocks. This is remarkably exemplified on the Tenasserim coast, where the hard granite, being more resistant, forms the former and the Mergui Series the latter.

It has been observed elsewhere that the south coast of Burma is gaining ground, as the rivers bring down detritus and deposit it in the sea, thus making it shallower, and ultimately converting the coastal fringes into land. Similarly, the rivers of South Tenasserim are silting up some of the shallow channels of the sea adjoining the mainland, and they may ultimately link up some of the nearby islands with the mainland. However, at the mouth of the Sittang the sea has eroded away a fairly large tract of land in the Kyaikto subdivision of the Thaton district, while a large area has been added to the Pegu district as a result of the shifting of the Sittang river towards the east. The sea has gained considerably higher up the river, and its effect is felt over much greater areas to the north than it was about two decades ago. Subsidence along the coast also means the disappearance of land under water, as has happened along the coast of Mergui, which is very irregular and is traversed by a network of creeks.

To sum up, as a result of heavy rainfall, high temperature and luxuriant vegetation, the rock is found decomposed to remarkable depths, so much so that sometimes it is impossible to find fresh rock for long stretches on the surface, except in stream-courses. The circulating subsoil water, charged with carbonic and humic acids and the seasonal changes of water-logging and drying, bring about this decomposition very quickly. This is particularly true of the more humid regions of the Province. The decomposed rock, as remarked above, is easily cut into and carried away by rain and hill torrents.

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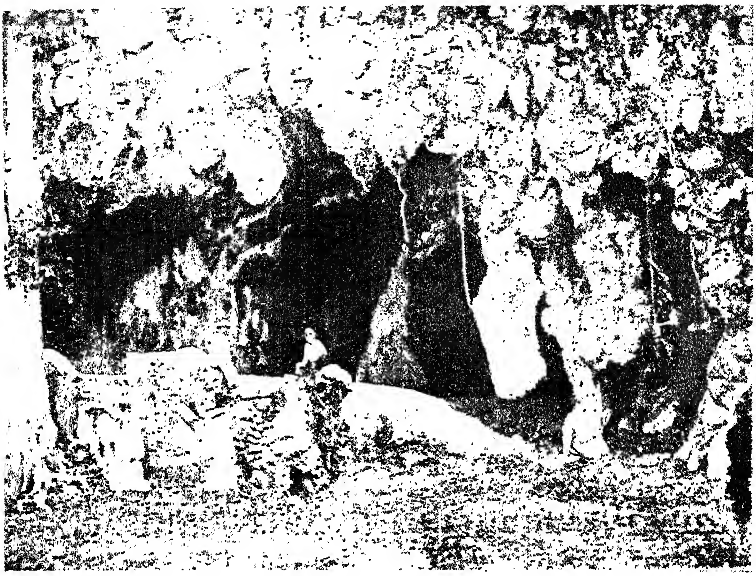
# CHAPTER VIII

## LIMESTONE CAVES

CAVES or hollow chambers in limestone regions are scattered all over the Shan States and Tenasserim. In fact, they are continued in western China towards the north, and are found also in Borneo to the south. A masterly account of the " Limestone Caves of Burma and the Malay Peninsula " has been published under the joint authorship of Annandale, Coggin Brown and Gravely. The caves are often separated from one another by long distances, and yet in many respects are remarkably uniform. The limestone formation in which these caves occur is most probably similar in origin throughout. The celebrated caves in the neighbourhood of Moulmein are situated in limestone probably of the same age as the younger limestone of the Shan States. The caves are all similarly formed : the great sheet of limestone, which once must have covered the country as already remarked, has been dissolved or otherwise removed so that only isolated hills now remain.

The best-known caves in Tenasserim occur in the neighbourhood of Moulmein, some of which (viz., those in the vicinity of Nyaungbinzeik village, Kyaikmaraw township, Amherst district) were visited by the writer in October 1927, and a short account was published in the *Burma Research Society Journal* for 1928. The limestone hills containing these caves rise abruptly from the plains. The latter, which are bounded by the Gyaing on the north, the Salween on the west, and the Attaran on the south, are devoted to paddy cultivation and during the rains are covered with water, resembling a vast " mimic sea " of fresh water with green patches resulting from the young rice plants. The sides of the hills (see Plate VIII, Fig. 2) are very steep and craggy, not infrequently having a sheer drop of several hundred

PLATE IX.



1.—SHOWING EXTERIOR OF THE FARM CAVES WITH PART OF THE NORTHERN ENTRANCE.

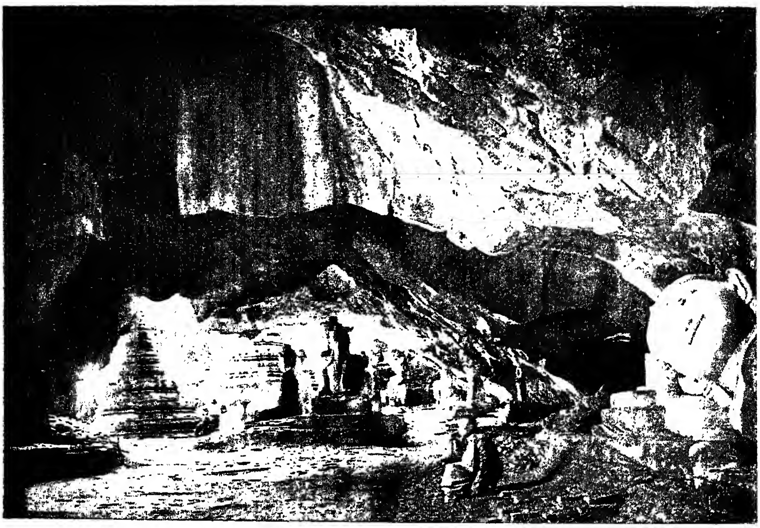


FIG. 2.—THE INTERIOR OF THE FARM CAVES IN THE NEIGHBOURHOOD OF NYAUNGBINZEIK, KYAIKMARAW TOWNSHIP, AMHERST DISTRICT.

feet. In places the sides are formed by overhanging cliffs. The limestone is highly jointed, sometimes in several directions, with the result that bedding is obscured. The vertical joints are widened by solution, and it is the vertical jointing combined with solution which explains the steep sides of the hills. The exposed surface is very rough, with sharp, steep edges. The bare, rugged nature of the hills is very characteristic, and reveals their true nature to a trained eye even from a long distance. Often no soil is to be seen at the surface, and the vegetation mostly consists of climbers, ferns and mosses. The surface often shows little rain-prints or solution hollows about half an inch deep, caused by the dissolving action of rain-water. Typical " grikes "—elongated solution hollows with sharp edges—also occur. Swallow holes are very common, and sometimes holes of about a foot in diameter lead to a huge cave below, several hundred feet in length and many feet in width. The caves and small hollows can be seen at all levels and in almost every limestone hill. The colour of the rock varies from a light grey to almost black, though light grey predominates. In places the limestone approaches marble in appearance.

**Caves in the Neighbourhood of Moulmein.**—The earliest description of any of the caves appears to be that of Captain Foley in his " Notes on Geology, etc., of the Country in the Neighbourhood of Maulmeng," published in the *Journal of the Asiatic Society of Bengal*, vol. v, pp. 269–281, 1836. He mentions as the principal caverns of the district those at Yetsey, Tyokhla, Jo-ka-beng, Damatha, Nyaungbinzeik, Phabia, and describes the Bhudda cave at Dhammathat (or Damatha) and a small cave, a little farther south near the summit of the hill. An account of the caves in the neighbourhood of Nyaungbinzeik is given below in some detail, since the features presented by the other caves in the district are more or less similar. Their picturesque scenery and colossal size are striking.

**Farm Caves.**—These caves (see Plate IX, Figs. 1 and 2) are situated in the Amherst district, a little more than 8 miles east-north-east of the important town of Moulmein. The limestone hills, being almost bare, present a sharp contrast to the neighbouring thickly-clad hill-ranges composed of sandstones and quartzite, sometimes covered by a cap of

laterite. There are four principal caves in the three hills. The general trend of these hills is north-west to south-east, and originally they must have formed a continuous chain, but they have now been separated and considerably lowered by denudation. The northernmost hill is Kayon hill (marked Karontaung on the old maps). It is about a mile long and one-third of a mile broad, and has been named after the village of Kayon, about one and a half miles north-west of the caves. The height of the hill is 589 feet. There are two very important caves here, both on the east side, though the author was informed by the *pongyi* (Burmese monk) that there was another big one on the west called Ma-saw-ma-ku. These caves are marked " Farm Caves " on the old map. The first cave, Kayon, is situated almost in the middle of the hill. There are three entrances to the cave, which consists of long tunnel-like halls with long, narrow and fantastic side chambers, and has been described fully by the author in the work cited above.

**Sadaw Cave.**—The Sadaw cave is situated at the southern end of the hill Karontaung. The entrance is narrow, about 8 feet in width, and is at a height of about 75 feet from the ground. This cave is far bigger than the first, but no images are to be found inside. The local people believe that when Bhudda assumed the form of an elephant he lived in this cave, and hence its name Sadaw, which in Burmese, means a royal elephant. On the right of the cave is an open amphitheatre with a number of subsidiary chambers. Not far from the entrance there is a sloping chamber on the left with a big "sky-light" about 15 feet in height and 8 feet in breadth, having two minor holes adjacent to it. This cave is, in fact, a large hall, several hundred feet in length, and in some places about 150 feet in width, which appears to have been subdivided into three chambers by the growth of pillars. The pillars are very fantastic in shape and of gigantic size, the circumference of some measuring as much as about 100 feet. The most remarkable of these are the umbrella-shaped stalagmites, which can accommodate a number of men inside the hollow. The floor of the cave is strewn with boulders that have fallen from above. In places, especially in the narrow side-chamber towards the right not far from the entrance, terraces have been cut out of the rock,

and form small reservoirs for the water trickling down from above. The water in these terraces and other small tanks is very cool and fresh. In the dark portions of the cave bats are abundant, and their excreta produces so bad a smell that it is almost impossible to stay long in the caves without experiencing nausea. The excreta can be used as a manure, and should be as useful as guano. This subject has been discussed by Burkill in a pamphlet, No. 1 in the *Agricultural Ledger* (Calcutta), 1911. But it is not certain whether the deposit, which is more than an inch thick in places, has ever been used for that purpose. In places the floor of the cave, on account of solution along the joints, has the appearance of a sun-cracked surface, especially near the small pools of water.

**Ale-ku.**—The next hill, called either Alekutaung or Taung-thonlôn, is a small conical hill with precipitous sides. At a distance its abrupt rise from the neighbouring flat land and its unique appearance make it closely resemble a volcanic plug, and the writer was struck by its great similarity to Taunggala, a volcanic plug on the south-western slope of Mount Popa. Ale-ku, or the middle cave, at the eastern base of the hill, is a very small one compared with the Sadaw cave. There is a semicircular chamber which is about 19 feet 8 inches wide at the entrance. The height of the cave is about 22 feet and the length 30 feet.

**Nga-ku** (fish cave) is situated at the northern end of the third hill ; it is almost inaccessible during the rainy season. It is some distance from the periphery of the hill, and between the entrance and the cave there is a fairly large amphitheatre with steep vertical walls. It is very likely that the open amphitheatre once formed part of the cave, and the collapsed roof is represented at the present day by the huge boulders strewn on the floor. Unfortunately the cave was entirely filled with water when visited by the writer, and so the interior could not be inspected, though there are two chambers, one to the west, the other to the south-east. The cave has been called Nga-ku by the Burmese on account of its low entrance, which bears some resemblance to a fish.

Another cave near Moulmein, mentioned by Captain Foley, is situated at Phabaung-taung, a limestone hill on the banks of the Ataran river ; this cave has a stream running through it.

A small cave occurs in the eastern side of Naungkwe *taung* (97° 55′, 15° 50′) with a bone bed, varying from a few inches to four feet thick, lying between the limestone floor and a covering of stalagmite from 8 inches to several feet thick. The bones are very plentiful, but mostly fragmentary and lie in great disorder in a matrix of reddish-brown earth. Dr. Pilgrim and Miss Bate of the British Museum recognised in the collection teeth belonging to species of bear, pig, ox, deer and antelope.

**Elephant Island.**—A small group of six marble rocks, known as Elephant Island, the highest and largest of which is 1,000 feet in altitude, and about one mile in length, occurs on the south-east side of Domel Island in the Mergui Archipelago. The group is oval-shaped, and rises very abruptly out of a depth of 5 fathoms. The great feature of the group is the birds'-nest caverns, which as a rule open out into the sea, the entrance being below high-water mark. At the south end of the largest island stands a ninepin of grey marble, 370 feet high, almost separated from the rest. This ninepin forms the western point of a nearby cove, 360 yards in diameter, which runs back into the big island. The sides of the cove rise steeply, though not perpendicularly, from it. At the head of the cove is a perpendicular wall of rock, over which the 1,000-foot summit can just be seen in the distance. At half-tide a tunnel opens under the wall of rock at the head of the cove; 250 feet in length, it is covered with dripping marine life, corallines, small corals, comatulae, sponges and sea-horses. This tunnel emerges into another circular basin with perpendicular sides, which gives the impression of the crater of a volcano. According to Carpenter it really represents a fallen-in cave, and these circular basins were themselves at one time the floors of huge caverns. The islands at one time were much higher, with cavern piled upon cavern, and the work of solution by moisture is slowly going on, pulling down these marble monuments of an ancient age. The islands are famous for the birds' nests which are considered a great delicacy by the Chinese.

**Karenni and Shan States.**—To the north of the Amherst and Thaton districts the limestone stretches through Karenni into the Shan States, and caves are found along the edge of the hills bordering the Shan States. These caves are well known, as

PLATE X.

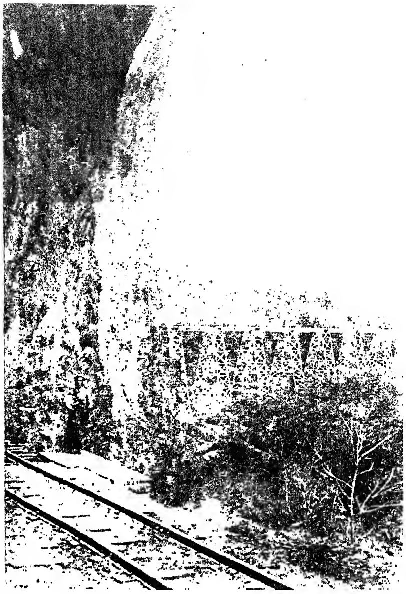


Fig. 1.—THE GOKTEIK GORGE, in PLATEAU LIMESTONE, NORTHERN SHAN STATES.

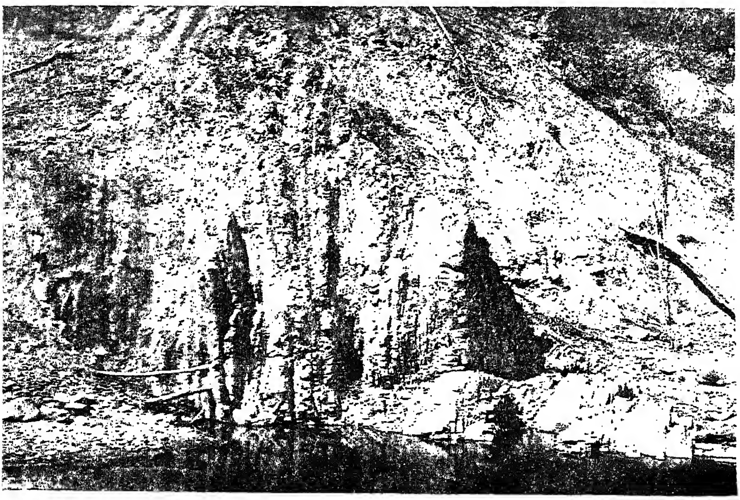


Fig. 2.—EOCENE SHALES, KALEWA.

Notice their vertical character as one approaches the main folded belt of the Chin Hills.

they yield large quantities of bat guano which is used as a fertilizer. C. S. Middlemiss has given a graphic description, reproduced below, of the limestones in the neighbourhood of Kalaw. "The dark-grey limestone frequently weathers almost black into sharp-edged honey-combed masses, into pinnacled crags, weather-beaten towers and walls: into deep basins and swallow holes (often as regular and circular as a gigantic amphitheatre, but sometimes funnel-shaped): into strange valley systems without connection of one with the other, and that often end mysteriously either as underground passages down which streams precipitate themselves and become lost, or as marshes and lakes where evaporation, helped out no doubt by subterranean percolation, causes a disappearance of the water: into innumerable caves and passages beneath the ground, some now high and dry from the waters that caused them and locally mined for the nitrates that have accumulated upon the floors from the decomposition of cave animal deposits, others used as show places and temples: others again, unknown to fame and rich in their virgin beauty of stalactite growth."

**Caverns and "Natural Bridges."**—It has already been mentioned that limestone occupies by far the greater portion of the Northern Shan States; but on account of the crushed and shattered nature of the rock, caves are rare, since the overlying strata will subside if hollowed out from within. The celebrated cave familiar to tourists to the Gokteik gorge (see Plate X, Fig. 1), situated beneath the railway viaduct, is not scooped out of the solid rock, but is roofed over by a deposit of travertine to the cliffs on either side. There are several of these so-called "natural bridges" in the Shan States, and in some cases the roof may be of solid rock. According to La Touche this appears to be so with the one on the Nam-sam stream, about three miles north-west of Hsipaw.

In the limestone plateau of the Shan States there occur several depressions in the surface, often of great extent, the drainage of which sinks underground. These depressions vary greatly in size, from "pipes" of a few feet in diameter to "swallow holes" and funnel-shaped "punch bowls," of which the latter are by far the more common, and from these to

enclosed valleys, several miles in length and breadth, traversed by running streams. These phenomena are due to the underground solution of the rock and the consequent settling down of the roof of a cavity or a cavern too weak to support its own weight. The smaller "punch-bowls" are generally seen in largest number along the crests of limestone scarps, when the water finds an easy outlet on the face of the cliff, *e.g.* along the edge of the great scarp that runs south from the railway at Kyauk-kyan near Nawngkio, to the Nam-tu. Lord Lamington has described the disappearance of a stream at Mong Hang in the Southern Shan States. The cave where the river enters on its subterranean course is in a sheer face of rock, some 200 feet high. The height of the cave is about 140 feet, its width at the entrance 300 feet, broadening in the interior to nearly 500 feet; the depth is about 500 feet. At the right-hand bottom corner, a tunnel, at an angle of 45° with the cave, provides a passage for the river. In other cases the punch-bowls have no obvious connection with any scarp, and then are generally of larger dimensions.

**Shwe Male Cave.**—The cave at Shwe Male, near the foot of the hills about 8 miles east of the Irrawaddy at Singu, above Mandalay, was visited in 1855 by Sir Henry Yule and Dr. Thomas Oldham. It is a hall of considerable size, about 40 feet high, with some narrow side chambers. A few stalactites and stalagmites are seen. The entire length of the caves is not more than 100 yards. This cavern, however, is not in the Plateau Limestone, but in the crystalline limestone associated with the Archaean rocks of the Ruby Mines district.

**Sankywe Cave.**—A cave exists in the limestone hill with steep cliffs overlooking the Uyu river, opposite the village of Sankywe in the Jade Mines region, Myitkyina district. Small outcrops of limestone are ubiquitous in this area. As remarked above, limestones attain a considerable development in the Chinese province of Yunnan, and in the western parts of the province small caverns are sometimes found.

**Origin of Caves.**—The caves owe their origin to the solvent action of carbonated water on jointed limestones. The water percolates through the joints and dissolves the rock, leaving hollow chambers. The following statement made by Temple is

erroneous: "The Farm caves, like those mentioned in this paper, are situated in isolated hills of limestone rock which rise picturesquely and abruptly out of the surrounding alluvial plain and were excavated by the sea at no remote geological period." The author considered this very carefully in the field, and has come to the conclusion that the explanation suggested by Temple is not correct. The hollow chambers or caves are to be seen at all heights, and sometimes the small entrances lead to colossal chambers inside; *e.g.* the entrance of Sadaw-ku is only about 8 feet, while the cave inside at a distance of several hundred feet from the entrance continues to be very broad; sometimes the width is over 80 feet, with a similar height. This must indicate that the caves owe their origin to an agent working from within. The caves are getting larger even to-day, while the stalactites and stalagmites are also growing in size, and in places new ones are springing up. In places the growth of these pillars is cutting off or partly closing the passages leading to some of the subsidiary chambers.

Great interest generally attaches to the caves on account of their scenery, highly specialised fauna and remains of bones of their old inhabitants. In Burma, unfortunately, these have not received as much attention as they deserve.

Apart from the caves in limestone regions, other caves are to be found on the sea-coast, where the action of the waves, tides and currents has detached rock-masses and carved out hollows. The writer observed such caverns in the quartzites of the Mergui Series on the north side of King Island in the Mergui Archipelago.

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# CHAPTER IX

## COASTLINE

Burma has a very long coastline, extending for about 1,200 miles from north of Akyab to Victoria Point, but much of it is dangerous for navigators. Except for the deltas it is mostly rugged and rocky, fringed with rocky or swampy islands and sunken reefs, while half-submerged rocks are a serious danger to shipping.

**The Arakan Coastline.**—The Arakan coastline is of the type known to geographers as the " Pacific Coastline," since coastlines of this character are prevalent round the shores of the Pacific Ocean. The " grain " of the country, that is to say the trend of folding of the rocks, is parallel to the coastline ; so that there are long ridges formed of outcrops of such hard rocks as sandstones, separated by long hollows marking the outcrops of softer rocks. Where such a country has been invaded by the sea, or " drowned," the ridges form long, narrow, rocky islands or peninsulas, separated by a network of estuaries and creeks communicating with one another and the sea. This is the characteristic form of the coast stretching southwards from Akyab as far as Sandoway. In addition, where marine denudation has attacked areas of softer rocks, there are mud flats frequently occupied by mangrove forests. Some of the outcrops, especially where the folding has been only slight, have been worn down by subaerial denudation to form large, low islands, such as Ramri Island and Cheduba. Southwards from the Sandoway river the coastline has fewer islands, but presents a rugged and rocky face to the ocean, with formidable headlands and dangerous reefs. Here and there are sandy bays, usually at the mouth of mountain torrents, rushing down from gently undulating downs.

**The Southern Coast.**—From Cape Negrais the coastline runs eastwards and entirely changes in character. The Arakan coastline has been shaped by earth movement aided by marine erosion, and is therefore rocky, while the coastline fronting the Gulf of Martaban, including the mouths of the Irrawaddy, is due to the deposition of silt brought down by the rivers. Here the formidable rocky coast of Arakan gives place to the flat, rounded outlines of the delta. The actual seaward margin of the alluvial flats of the delta is formed by a sandy beach with numerous shoals and shallow water, fringed by mangrove swamps. On account of these, large vessels cannot approach within several miles of the shore, except along the submerged channels which mark the main streams of water from the Irrawaddy.

**Tenasserim Coastline.**—A little south of the mouth of the Sittang the coast again assumes its north-south trend. From Amherst southwards the coast is fringed with reefs, whilst northwards mud flats with mangrove swamps are the rule. In places the Tenasserim coast is lined with a belt of mangrove swamps, which lie bare at low tide. South of the mouth of the Tavoy river the coastline is studded with numerous islands of the Mergui Archipelago, the chief features of which are described elsewhere. Here, too, the coast is broken by a network of creeks and inlets of the sea. It has again a Pacific type of outline, due probably to mountain building movements which occurred towards the close of the Tertiary period. Such movements generally take place close to the margin of a continental mass, and they may result in the elevation of mountain ranges beneath the area. Thus the higher parts of the ranges above sea-level, as noted above, represent the numerous islands of the Mergui Archipelago. Indeed, the coast itself is cut into islands by the tortuous channels into which the rivers divide as soon as they leave the higher ground. These inner islands are mere morasses of mangrove and slime, but the outer islands rise well from the blue sea, some of them to a height of several hundred feet. The elongated ridges of granite form rocky peninsulas or islands; the softer rocks of the Mergui Series have been worn down to form mud flats or low islands. Dense forest comes to within 20 or 30 feet above high-water

level, then there is a bare slope of granite to half-tide level, and below that a pile of boulders.

Almost every bay in the Tavoy district has a crescentic sandspit with a lagoon behind it; the entrance to the lagoon is at the south end of the spit. One description, as given by Dr. Coggin Brown and Dr. Heron, is common to all. The sandspit is composed of coarse sand, partly wave-borne and partly wind-blown, and it extends with rather a steep slope from half-tide level to the highest point to which the waves can reach. The spit becomes bound by grass, etc., and supports groves of casuarina and salt-loving shrubs. The lagoon behind may be open water, mangrove swamp or salt marsh flooded only at spring tides, according to how far silting up has proceeded. Accumulation proceeds very rapidly as a result of the incoming of the silt twice a day. Burrowing organisms bring up mud from below, and on their death their shells add to the accumulation. Thus every stage may be seen, from a sandspit with open water behind to a flat just above high-water level.

The position of the entrance channel near the south—sheltered while the north is exposed—is perhaps to be explained by the angle at which the monsoon current meets the coast. The bays face westwards, and the monsoon waves come from the south or south-west, so that the drift of material is away from the southern end. Once the sandbank is established, the tidal drift. which sets parallel to the coast, tends rapidly to lengthen it.

## ISLANDS AND ARCHIPELAGOES.

In general it may be said that all the islands off the coast of Burma owe their origin to the erosion and subsidence of land, and at one time they must have been connected with the mainland, as some of them are now separated from the latter only by a very shallow channel. This is clearly substantiated by the fact that the geology of the islands is identical with that of the mainland.

**Ramri Group.**—On the Arakan coast, off the mouth of the Kaladan river in Akyab, there are three islands called the Baronga Islands, which are merely three detached ranges of low hills, running southwards into the sea. Farther south

we have the Ramri group of islands, which includes the important islands of Ramri and Cheduba, with several islets in the neighbourhood. Orographically and geologically they are really a part of the Arakan range, and the hilly islands of Baronga simply constitute the outliers, or detached portions of the western flank of the range. Ramri is separated merely by a narrow creek from the mainland, to which the whole group would be connected by an elevation of a few fathoms. Cheduba, which lies to the south of Ramri Island, is a fertile, well-wooded island of moderate height and irregular outline. A strip of level plain, but little raised above the sea, extends around its coasts, and has a far greater width on the east than on the west; within this lie irregular, low, undulating hills, varying in height from 50 to 500 feet, while near the south part of the island, a height of 1,700 feet is attained.

**Diamond and Negrais Islands.**—Off the southern coast of Burma are the islands of Diamond and Negrais, at the mouth of the Bassein river, and there is not the slightest doubt that the raised portions (visible above the water) are the continuation of the Arakan Yomas towards the south, while the intervening land is submerged.

**The Andamans and Nicobars.**—The islands of the Andamans and Nicobars are situated on the submarine ridge which connects Java and Sumatra with the Arakan Yoma of Burma in the north. These islands are simply the higher portions of the ridge seen above water.

The Andamans consist of four large islands and several smaller ones, and lie about 200 miles west of the Tenasserim coast of Burma. They are situated between lat. 10° 30′ and 13° 30′ N., and long. 92° 15′ and 93° 10′ E. The largest and most important group of islands is termed the Great Andaman. Its configuration is rather peculiar. It appears at first sight to be one large island, but in reality consists of three islands separated by narrow channels. About 20 miles to the south is another island, considerably smaller, called the Little Andaman. Numerous other islets rise above the surface of the water in the neighbourhood, and some of them are very pretty and picturesque, and look like green oases on the desert surface of the ocean. The entire group is fringed by coral reefs, which

sometimes extend for many miles into the sea and render navigation in places more than usually dangerous. The highest hills are nearer the east coast than the west, and the slopes are steeper on the east—a feature observed also in the submarine ridge which forms the continuation of the group (see Fig. 20). The coastline is much indented, and the openings are much larger and more numerous on the east coast than on the west. From these bays creeks run inland for several miles.

All the islands are covered with the densest tropical vegetation from the seashore to the summit of the highest hill, except where clearings have been effected, especially in the neighbourhood of Port Blair. Extensive mangrove swamps are found in all but the most exposed parts of the coastline.

The Great Andaman, as remarked above, consists of three islands, viz. the North, Middle and South Andamans. Middle Andaman is separated from North Andaman by Austin Strait and from South Andaman by Homfray Strait. North Andaman island is about 40 miles in length, and possesses an average breadth of 14 miles. On this island is situated Mount Saddle (2,400 feet), the highest point in the group. The Middle Island is from 15 to 18 miles in width and about 40 miles in length. The eastern coastline comprises a series of rocky spurs separating stretches of sandy seashore, often fringed by coral reef. The southern portion is, however, much more highly indented by creeks reaching inland for a considerable distance and lined by mangrove swamps. South Andaman is 40 miles in length and the average breadth is from 15 to 18 miles. On its eastern side are two spacious harbours, Port Meadows and Port Blair. There are also two harbours on the western coast. The Homfray Strait, which separates South Andaman from Middle Andaman, is navigable throughout its extent, and near its western extremity forms a very fine harbour. On the south side of South Andaman, from which it is separated by Macpherson's Strait, is Rutland Island, which is nearly 10 miles in length by 4 miles in breadth. Its northern extremity rises to a considerable height.

Ritchie's Archipelago includes the group of islands lying from 10 to 15 miles to the east of the Middle and South Andaman Islands, between lat. 12° 20′ and 11° 46′ N. The main islands

of the group run in a general north-south direction, and are separated by shallow creeks, along the shores of which mangrove swamps flourish.

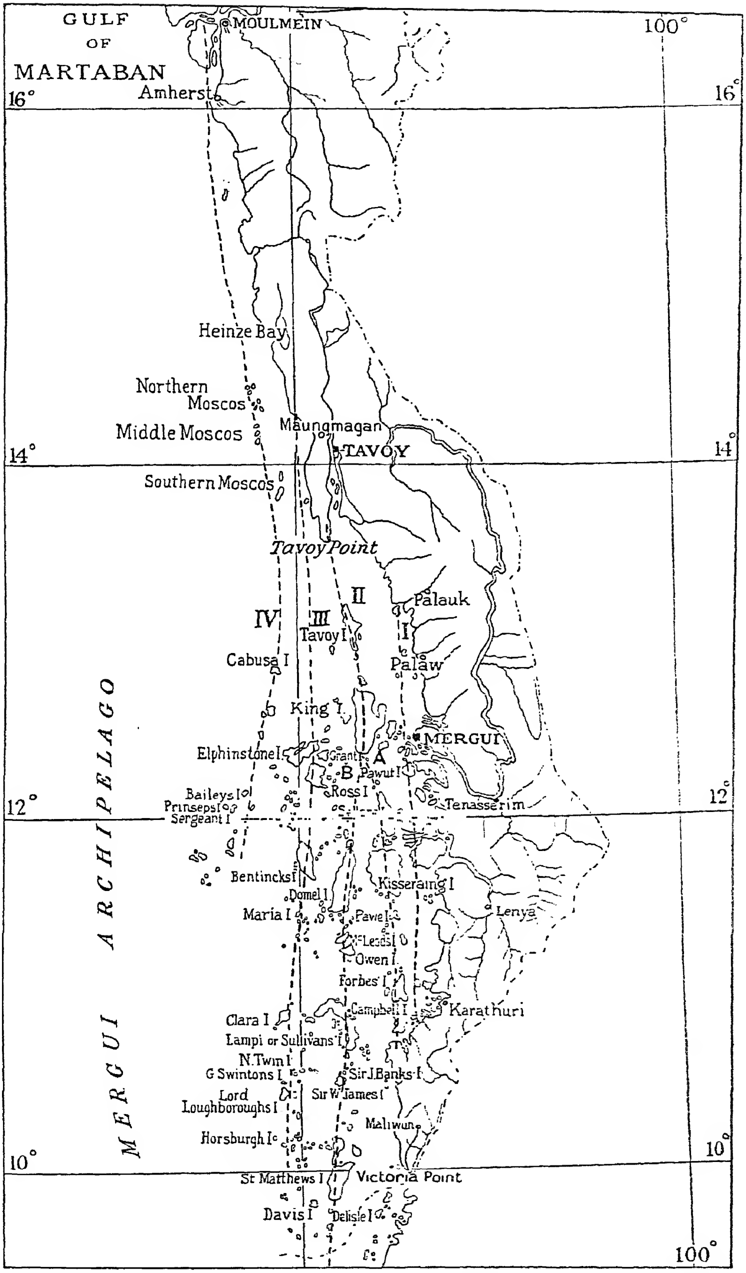
All these islands are a southern continuation of the Arakan Yoma, and represent the peaks of an important oceanic mountain arc, seen above the waters of the Bay of Bengal. Their link with the western hill ranges of Burma is further substantiated by the fact that the geological constitution of the rocks of the Andaman Islands is identical with that of the Arakan Yoma.

East of Middle Andaman, the largest of the group, is the remarkable active volcano of Barren Island, which is 1,700 feet high and 7 miles in circumference. Narcondam, another volcanic islet, 2,330 feet above the sea, is clothed with dense vegetation from the beach to the summit of the cone, which shows no trace of a crater, and which in any case has long been extinct.

The Nicobars are 550 miles from Rangoon and nearer Sumatra than the Andamans. They are really a continuation of the Andaman arc to the south, reaching a point as far south as 6° 45′ N. lat. They form two groups of islands, separated by the Sombrera channel.

**Islands off the Moulmein Coast.**—Off the coast of Tenasserim there are some big islands, Bilugyun, in the neighbourhood of Moulmein, being the largest. The geological constitution of this island is exactly the same as that of the mainland, from which it is only separated by the southern and more important branch of the great Salween, which serves as a means of approach to the port of Moulmein. Opposite the rocky coast of Amherst is the beautiful, small Green Island, where a lighthouse has been erected to warn ships of the numerous dangerous reefs and to guide them into the channel to Moulmein. Farther south are the three Moscos Islands and Tavoy Island, which really form a northern continuation of the Mergui Archipelago.

**The Mergui Archipelago.**—There are about 900 islands in all forming the Mergui Archipelago. These islands are of various sizes, ranging from King Island, with an area of 170 square miles, to mere hummocks of rock projecting above the surface




G. 12.—Showing the tectonic lines of the Mergui Archipelago.

of the water. They are simply the higher portions of definite ridges, and are all connected beneath the sea. The whole Archipelago is within the 50-fathom line. According to Sethu Rama Rao the formation of small islands is proceeding even to-day with the help of what is known as a *galet*—a Burmese word for a very narrow strait connecting two arms of the sea and dividing two islands. Tidal wave and marine erosion work on the rocks at the source of two streams flowing in opposite directions on the saddle-like ridge between them till they are base-levelled. Later the channel is deepened and a regular connection is formed, through which small boats can pass at high tides only. At low tide the ridge of the strait is either dry or covered with shallow water.

The islands appear to lie on four tectonic lines. The innermost line (marked I on Fig. 12) appears to start from an island a little south of Palauk stream, and runs southwards, terminating in the islands near Karathuri. Secondly, the line of islands which breaks off from the mainland at Tavoy Point is very conspicuous. The highest points on this line occur on Tavoy Island, King Island (2,515 feet) and Domel Island (2,236 feet). Other important islands on this line are the Sullivans or Lampi, and St. Matthew's. This line joins the mainland again at about lat. 9° N., or a little below the latitude of Middle Island. Another subsidiary line (marked II on Fig. 12) shoots off from King Island, continues through the islands of Sellore, Kisseraing, Malcolm, Forbes, etc., joining the mainland south of the Campbell Islands. The third line appears to start from a point near Maungmagan, and passes through the islands in the Tavoy district, Elphinstone, Ross, Bentick's, Maria, Clara, Lord Loughborough's, etc., and ends near the Sayer Islands in the extreme south where the sea deepens abruptly to the west. On the outermost line are the islands of Cabusa, Tenasserim, Bailey's, Prinseps, Sargeant, Hayes, etc. These four lines are shown on Fig. 12. There are a few islands that appear to occupy a somewhat intermediate position, though in reality they are detached portions of the islands mentioned. These chains of islands must have formed ridges, while the intervening portions now under water may represent the tectonic valleys. Large islands, such as the Kisseraing,

Domel, Sullivan and Forbes, have very indented coastlines forming a series of bays, with intervening promontories.

The coastline of the mainland and some of the islands is fringed by extensive flats of soft mud, exposed for miles at low tide and submerged at high tide. In the outer islands the coast is usually a sandy beach, but that of the mainland consists generally of laterite.

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# CHAPTER X

## STRATIGRAPHY OF BURMA—INTRODUCTORY

In Burma we have two marked geological provinces : the Eastern and the Western. The former constitutes the Shan-Tenasserim region, where, beginning with the Archaean period, we have an almost complete sequence of deposits right up to the end of the Cretaceous, whilst the Western province comprises the Arakan-Naga region with the valleys of the Irrawaddy and the Chindwin.

The nucleus of Burma is exposed in those parts of the Ruby Mines area, Shan States and Tenasserim, where the Archaean gneisses, etc., described in the next chapter, are found. These earliest rocks were then submerged, and the unfossiliferous deposits of the Chaung Magyi Series of the Federated Shan States and perhaps the Mergui Series of Tenasserim were laid down. Subsequently these deposits were upheaved, the sea retired, and the mighty chisel of nature began its erosive work. After some time the land was submerged again beneath the sea. In the Shan States excellent records of the geological history during the Palaeozoic and Mesozoic eras are preserved, with a very rich faunal wealth which presents an absorbing interest to a student of geology. Towards the end of the Mesozoic era, though Burma proper was still submerged, the sea retired from the Shan plateau, the western edge of which must then have formed the coastline. The whole area, with the exception of several old lake basins, the present-day remnants of which are represented by the Inle and other lakes, has been a land mass since Cretaceous times. The Tertiary deposits of this region are fragmentary, and were most probably deposited in these lake basins or along the present river valleys.

The Western region, comprising the Arakan-Naga province,

includes part of the Irrawaddy and Chindwin valleys. In it the Archaean and Palaeozoic rocks have not yet been discovered, and the first formation of this region, which has been definitely dated, belongs to the Triassic period. Undoubted Jurassic fossils have also still to be found. But from the Cretaceous onwards we have a complete range of deposits. At about the time when the Shan plateau was first upheaved this region also emerged in the form of a low, narrow island, which constituted a barrier between India and Burma from Tertiary times onwards.

The upheaval of the Arakan Yoma divided the sea into two gulfs, one marking the Central Belt of Burma, known as the "Burmese gulf," and another on the west, generally called the "Assamese gulf." The former was open to the sea in the south, but towards the north, as explained in detail later, several great rivers, possibly the ancestors of the present Irrawaddy and Chindwin, poured in their sediments. According to Dr. Cotter and Dr. L. Dudley Stamp the whole history of the Tertiary period has been the infilling of this gulf by river-borne sediments from the north and by marine sediments in the south. This infilling is analogous to the process now going on in the Gulf of Martaban, which is getting shallower and receding southwards every year. The gradual infilling of the trough was, however, interrupted at intervals by lateral folding movements. It was in these two gulfs that the oil-bearing rocks of the Central Belt of Burma, the Arakan coast and Assam, were laid down. The gulfs, after the sea had receded from them, were occupied by rivers whose sediments also were folded by later movements still.

The greater part of the Central Belt became a land mass almost at the beginning of the present geological era.

The present or the last chapter of the history of the making of Burma, which is still incomplete, is constituted by the deposition of the alluvial sands and clays forming the deltas of the Irrawaddy and the Sittang. Stretches of river alluvium also exist in the Central Belt and other parts of Burma.

It will, therefore, appear that the Archaean, Palaeozoic and Mesozoic rocks are very well developed in the Eastern region, comprising parts of Upper Burma, the Federated Shan States, Karenni and Tennasserim. In the Arakan-Naga region Meso-

zoic and Tertiary deposits are found, while in the *Central Belt* the Tertiary and Quaternary sequence is excellently developed.

The following table gives a list of the geological formations as found in the two regions, with their probable equivalents in India and adjacent regions on the west, and in Malaya and the Dutch East Indies, farther east, in descending order :

| Age. | Arakan-Naga region, including Irrawaddy-Chindwin Basin. | Bhamo, Mogok, Federated Shan States, Karenni and Tenasserim. | India and the adjacent regions. | Malaya and Dutch East Indies. |
|---|---|---|---|---|
| Recent and sub-recent. | Newer alluvium of the Irrawaddy, Chindwin, and the Sittang, etc. | Travertine deposits and calcareous tufa, alluvium, gem- and gold-bearing gravels of Mogok. | Newer alluvium (Khaddar) of the Indus and Ganges, and other rivers, blown sand, loess. | Recent alluvium on both coasts of the Peninsula and in the river valleys. |
| Pleistocene. | Older alluvium; Plateau gravels, the Uru Boulder and Tanai Hka Boulder conglomerates. Igneous rocks of Mount Popa, Lower Chindwin and the Jade Mines area. | Conglomerates and gravels of various valleys. | The Bhangar of the Indo-Gangetic alluvium, loess of Baluchistan and Salt Range, Upper Karewas of Kashmir, older alluvium of the Narbada, Godavari, etc., low-level laterite, Cuddalore sandstone, Porbander sandstone. | High-level alluvium, possibly Pleistocene. In Kinta it is tin-bearing. |
| Pliocene and Pontian. | Irrawaddy series; interbedded lavas and tuffs and ashes in places. | Tertiary sands, pebble beds and lignites of Shan States; oil shales of Amherst. Tertiary basins of Tenasserim. These may at least in part belong to the Pleistocene period. | Siwalik system of the Himalayas and Salt Range, Manchar system of Sind, high level laterite of the Peninsula. | In the Dutch East Indies and British Borneo there is a great development of Tertiary rocks. |
| Miocene. | Upper and Middle Pegu beds, Akauktaung, Pyalo and Singu stages. | | | Tertiary bedded rocks with coal—may be later in age. |

| Age. | Arakan-Naga region, including Irrawaddy-Chindwin Basin. | Bhamo, Mogok, Federated Shan States, Karenni and Tenasserim. | India and the adjacent regions. | Malaya and Dutch East Indies. |
|---|---|---|---|---|
| Oliogocene | Lower Pegu beds; Padaung and Schwezetaw stages. | | Gaj series of Sind, Nari series of Cutch and Sind. | |
| Eocene—Upper. | Yaw and Pondaung stages, Nummulitic Sandstone series in Henzada and other districts. | | Kirthar series of Assam, Sind and Baluchistan; Nummulitic limestone of Salt Range, Surat and Broach; Sabathu and Charat series of Outer Himalayas. | Nanggulan series of Java, etc. |
| Eocene—Middle. | Tabyin and Tilin stages. | | Laki series of Assam, Sind, Baluchistan and Salt Range. | |
| Eocene—Lower. | Laungshe and Paunggyi stages. | | Ranikot series of Sind. | |
| Cretaceous. | Negrais series, Chin shales (in part) Mai series, serpentine intrusions of the Arakan Yoma, etc. (Some of these intrusions, both in Burma and India, are of early Eocene age.) | "Red Beds" (?) of Kalaw, granites of Tenasserim, Yamethin and Kyaukse and other districts in the north. | Cretaceous of Central Himalayas with plutonic and volcanic rocks, *Cardita beaumonti* beds, Cretaceous of West Salt Range, South-east Coast Cretaceous, Deccan Trap, intrusion of serpentine, gabbros of Baluchistan. | Granite, hornblende-granite, syenite, diorite and small exposures of gabbro and norite. |

| Age. | Arakan-Naga region, including Irrawaddy-Chindwin Basin. | Bhamo, Mogok, Federated Shan States, Karenni and Tenasserim. | India and the adjacent regions. | Malaya and Dutch East Indies. |
|---|---|---|---|---|
| Jurassic. | | Namyau series of the Northern Shan States; Loi-an series of the Southern Shan States; the Red Sandstone series of the Amherst and Mergui districts. | Saighan beds of Afghanistan, Jurassic limestones of Baluchistan. Marine Jurassic of Cutch, Jurassic of the Himalayas, Upper and Middle Jurassic of the West Salt Range—Chichali Range. | |
| Rhaetic. | | Napeng beds of the Northern Shan States. | Para stage of the Central Himalayas. | |
| Triassic. | Axial series, *Halobia* limestone of Pyagyi (Arakan Yoma). | *Halobia* limestone of Karenni, Kamawkala limestone of the Amherst District. | Trias of Salt Range and the Himalayas. | Triassic quartzites and shales of Malaya. Similar rocks and limestones occur in the Dutch East Indies. |
| Permo-Carboniferous. | | Upper Plateau Limestone of the Shan States; Moulmein limestone; Tharabwin limestone of the Mergui district. | Middle Productus Limestone of the Salt Range, Central Himalaya. Fusulina limestone of Baluchistan. | The Raub series, comprising limestone, calcareous shales, etc., of Malaya and similar rocks of Sumatra—Carboniferous and Permo-Carboniferous in age. Quartzites and shales of Lower Carboniferous age. |

| Age. | Arakan-Naga region, including Irrawaddy-Chindwin Basin. | Bhamo, Mogok, Federated Shan States, Karenni and Tenasserim. | India and the adjacent regions. | Malaya and Dutch East Indies. |
|---|---|---|---|---|
| Devonian. | | Lower Plateau Limestone of the Shan States, including Padaukpin limestone and Wetwin shales. | Devonian (Muth quartzites) of Spiti and Kashmir; Devonian limestones of Hazara and Chitral. | |
| Silurian. | | Zebyingyi beds, Namhsim series, Panghsapye graptolite band. | Silurian of Spiti and Kashmir. | |
| Ordovician. | | Nyaungbaw limestone; Hwe Maung shales, Naungkangyi series, Nwetaung sandstones. Mawson series, Orthoceras beds and Pindaya beds of the Southern Shan States. | Ordovicians of Spiti and Kashmir. | |
| Cambrian. | | Bawdwin volcanic series, Chaung Magyi series(?), Mica Schists, Mergui series (?) Tenasserim volcanic rocks. | Cambrian of the Salt Range, Haimanta system of Central Himalayas. | |
| Archaean—Huronian. | | Crystalline limestones of the Ruby Mines district, etc. | Dharwar system. | |
| Archaean—Lewisian. | | Mogok and Dawna gneisses, etc., with the igneous intrusions. | Charnockite gneisses and granite of South India, Bundelkhand gneiss, Bengal gneiss. | |

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# CHAPTER XI

## ARCHAEAN SYSTEM

### I. MOGOK GNEISSES

THE first chapter of the geological history of Burma begins with the formation of the oldest rocks found in the province, the Mogok and Dawna gneisses. The first form a zone of crystalline rocks along part of the margin of the Shan plateau. Fortunately, on account of the association of the celebrated rubies, sapphires and spinels of Burma with the ancient gneisses and connected crystalline limestones—these rocks in the neighbourhood of Mogok have been studied in great detail by Barrington Brown and Judd. Lately the detailed survey of the Mogok Stone Tract has been undertaken by the officers of the Geological Survey of India, among whom the names of Drs. L. L. Fermor, Coggin Brown and A. K. Banerji deserve mention. The investigation is now being completed by E. L. G. Clegg and others; so very soon our knowledge of this most interesting region is likely to be enriched by the publication of the results of this band of workers.

**Distribution.**—The Mogok gneisses occupy a great portion of the old Ruby Mines district; the high ground especially is composed of Archaean crystalline rocks. The southern boundary of the gneisses and schists of the Ruby Mines area is well defined by the valley of the Nampai (Nampi or Mobi *chaung*). To the north of this river they extend in a succession of parallel ranges from north-east to south-west, which is also the strike trend of the rocks themselves. Proceeding northwards the crests rise from elevations of 2,000 to 3,500 feet to heights of 4,000 to 7,000 above sea-level, until they culminate in the highest peak of the area, Taung Mè, 7,544 feet above sea-level.

On the east the Nampek or the Chaung Magyi river forms the boundary, and near Sedaw there is a turn almost at right angles in a western direction. Between the eastern bank of the Irrawaddy and the Nampek the general strike is still north-east—south-west; but on the western bank of the Irrawaddy there is a long band of gneiss which extends northwards from Sagaing, and forms most of the low ranges of hills which run almost parallel to the river. Here there is a change in the strike to the south, which is definitely noticeable near Wabayachaung. The outcrops of crystalline rocks on the eastern side of the Irrawaddy, as at Sagyin hill, Mandalay hill and near Kyaukse, are also believed to be of Archaean age. Southwards of this they form a continuous band, from 12 miles upwards in width, along the edge of the Southern Shan plateau, extending to the sea near Moulmein. No crystalline limestones of the Mogok variety have been reported from the more southern regions. The northern and north-eastern boundaries are not definitely known, but the Mogok gneisses are thought to be continuous with the gneisses of the country north of Bhamo, as reported by Greisbach, and with the biotite-gneisses and crystalline limestones of the frontier ranges between Bhamo and Teng Yueh.

The crystalline limestones associated with the gneisses and schists form long, parallel, lenticular or oval bands, in the main between lat. 22° 45′ and 23° N. and long. 96° and 96° 40′ E.

**Petrological Constitution.**—La Touche gave the name of Mogok Gneiss to a series of scapolite-garnet-biotite-gneisses with bands of crystalline limestone of Archaean age occurring in the Ruby Mines area of Burma. Lately A. K. Banerji has classified the rocks of the Mogok neighbourhood into the following groups, though their exact relationships as yet are unknown:

Mogok Series,
Acid gneiss,
Syenite and nepheline-bearing rocks,
Minor intrusions.

According to Banerji the Mogok Series seems to be the oldest in the area, and represents a highly metamorphosed group,

partly of sedimentary origin. The true relationships of the acid gneiss are not known, but tentatively it is regarded as intrusive into the Mogok Series. If this proves to be the case, then the basement on which the Mogok Series was deposited will have to be sought. The alkali rocks and the granite pegmatites are taken as the latest phases of the intrusion.

The normal variety of the Archaean gneiss is a dark green or greyish, coarse or fine-grained, garnet-bearing, biotite-gneiss with or without sillimanite. It is well foliated and contorted ; a bedded appearance probably due to coarse jointing is seen in some localities. The average rock consists of quartz and felspar (both orthoclase and plagioclase), often highly altered to kaolin, and dark mica. The accessories are garnet, zircon and apatite, and the first two occur in abundance. In the road-cuttings the decomposed rock shows numerous stringers of aplitic and pegmatitic material injected into it. In places it passes into garnet-graphite-sillimanite rock, quartz-sillimanite rock and iron-stained quartzite.

By the gradual diminution and final elimination of the felspar the gneiss passes into schist. More interesting types are provided by the occurrence of acid pegmatite, aplite and granulite veins and basic and ultrabasic rocks like pyroxene-gneisses and pyroxenites, which are closely interfoliated with the main mass of the rock.

**Acid Pegmatites.**—The acid intrusive veins, which are of varying texture, constitute pegmatites when the rock is coarse-grained, or aplites, which are either garnetiferous leptynites or true granulites, when fine-grained. The pegmatite usually exhibits a graphic texture, while the aplites show a fairly distinct granulitic texture. The felspar of the former type, which preponderates over the other minerals, viz., quartz and mica, often attains considerable dimensions and exhibits a strained condition. This mineral also shows the remarkable structure styled by the French petrographers "quartz de corrosion" ; inclusions of fibrolite are quite common ; alteration to moonstone, epidote, muscovite and, lastly, to kaolin, is observed frequently. When quartz occurs in sufficiently large quantity a close intergrowth between this mineral and the felspar is easily detected, and with the addition of mica

this rock becomes a graphic granite. The mica of this rock is usually muscovite.

**Garnet Granulites** are the commonest rocks in the neighbourhood of Mogok. They consist of garnet, quartz and felspar, which is mostly microperthite. In some cases garnet is absent, but on the other hand there is a type in which very fine biotite flakes besides garnet occur. The rock is used for building purposes in Mogok. In places where gemstones are worked boulders of these rocks are very often present. Almost everywhere they are invaded by pegmatite veins, ranging from a few inches to many feet across, and sometimes so permeated by smaller sheets and films along their folia as to afford examples of true *lit-par-lit* injection. Good examples occur in the quarries south-west of Mogok. According to Dr. L. L. Fermor the whole of this section may be regarded as a composite gneiss, suggesting, according to Professor Adams, a series of " highly altered and granitised sedimentary rocks," for both the garnetiferous biotite-granulites and the coarser biotite-gneiss are permeated throughout by them and by thick bands of intrusive quartz-felspar rock, and more rarely of tourmaline-pegmatite. The banding of the rock is due to more coarsely grained, lenticular quartz-felspar layers without biotite, which range up to half an inch in thickness ; the garnets are confined to these layers, and have been formed by interaction with the injected material. A. K. Banerji has described a garnet-graphite-sillimanite-granulite from near Bernardmyo. It approaches the felspar-bearing khondalites of Ceylon, except that the latter are stated by Professor Adams to carry no graphite.

**Pyroxene-Gneisses.**—Intercalated with the parent gneiss, though subordinately, are the masses and bands of the basic series, which are easily distinguishable from the former by their characteristic dark greenish-grey colour and greasy lustre. These are coarse-grained pyroxene-gneisses, pyroxene-scapolite-gneisses, fine-grained pyroxene-granulites and pyroxene-scapolite-granulites. The pyroxene-gneisses consist of plagioclase felspars, ranging from basic oligoclase to labradorite, an augite—either dark green or pale green when examined in thin sections—sphene and other accessories like zircon, corundum, graphite and apatite. Both the felspar and the pyroxene show

signs of alteration. Sometimes the pyroxene is accompanied by biotite or hornblende. In these rocks the felspathic element is totally subordinate to the dark mineral—enstatite or a non-pleochroic, purplish titaniferous augite. The pyroxene-granulites closely resemble the charnockite of India, but differ from it by the smaller proportion of the white to dark minerals. By the partial or complete alteration (werneritisation) of the felspar to scapolite, pyroxene-scapolite-gneisses are formed. With the increase of pyroxene and the disappearance of the alumino-alkaline silicates the basic gneisses pass into the ultrabasic pyroxenites, and the alteration of the last results in the formation of amphibolites.

**Peridotites.**—The peridotites are confined to the Bernardmyo area, where A. K. Banerji [1] found three separate intrusions which range in composition from dunite, with very few grains of enstatite, to enstatite-peridotite. The gem variety of olivine, the peridot, which is obtained from gravels near Bernardmyo, is evidently derived from these rocks. Boulders of pyroxene-hornblende rocks have been found also in the vicinity of Bernardmyo and near Pingu-taung.

**Syenitic Rocks.**—Syenitic rocks ranging from quartz-syenite to dioritic monzonite are of wide distribution. Cryptoperthite is abundant in some specimens, and in these myrmekite has been noticed. The felspar of the dioritic monzonite is predominantly andesine, and the pyroxene is either augite, aegerine-augite or aegerine. The accessories are apatite, sphene, zircon and iron-ores. The syenites are particularly well-developed in the amphitheatre between Mogok and Taungmè and around Lennu and Letha *taungs*. Other important intrusions of syenites are confined to the neighbourhood of Kyaukthinbaw *taung* and to the area immediately to the west of it. According to Banerji [2] there is a large laccolitic intrusion north of the village of Oongain, a peculiar feature of which is that bands of limestone seem to be caught up in it. They were first recognised in the field by Dr. L. L. Fermor and in the laboratory by Dr. J. A. Dunn. The syenite is usually augite-syenite. Most of the felspar is microperthite, but a little ortho-

[1] *Rec. Geol. Surv. Ind.*, vol. lxv, 1931, p. 84.

[2] *Rec. Geol. Surv. Ind.*, vol. lxvi, 1932, p. 94.

clase and albite are invariably present. According to Banerji two specimens show the presence of brown hornblende, in one of which biotite is present in addition. The accessories are sphene, apatite and zircon.

**Nepheline-Syenites and Gabbros.**—There is a small exposure of a nepheline-bearing rock very rich in dark minerals, north-west of the Lishaw village of Chaunggyi. No contact is visible, but it appears to be an independent intrusion. The following three types were recognised by Banerji [1]:

1. **Jacupirangite.**—This is a melanocratic rock which is very rich in dark minerals comprising titanaugite and brown basaltic hornblende. The other minerals are nepheline, orthoclase, plagioclase, and with calcite, pyrites and apatite as accessories. The rock differs from that of the type locality in containing felspars and hornblende.

2. **Ijolite.**—This rock is without felspar. Its minerals are nepheline, titanaugite and brown basaltic hornblende. According to Banerji it differs from that of the type locality in containing titanaugite instead of aegirine-augite and in containing hornblende.

3. **Titanaugite-hornblende-rock.**—The hornblende of this rock is a basaltic variety.

Near the same locality scattered boulders of a nepheline-corundum-syenite were found by Banerji. It consists of nepheline, orthoclase, albite, blue corundum or sapphire, green spinel or ceylonite and augite. The nepheline in places shows graphic intergrowth with felspar. In the same neighbourhood a nepheline-augite-syenite occurs in association with limestone. Some of these nepheline rocks, according to the same author, bear a close resemblance to the Sivamalai series of elaeolite-syenites and corundum-syenites of the Coimbatore district of Madras, described by Sir T. H. Holland.[2]

**Origin of the Nepheline-bearing Rocks.**—The formation of these rocks by the assimilation of limestone by basic magma is considered by Dr. L. L. Fermor [3] to lend support to the assimilation hypothesis. These nepheline-bearing rocks, containing also the

[1] *Rec. Geol. Surv. Ind.*, vol. lxvi, 1932, pp. 94-95.

[2] Holland, Sir T. H., *Mem. Geol. Surv. Ind.*, vol. xxx, 1901, p. 169.

[3] *Rec. Geol. Surv. Ind.*, vol. lxvi, 1932, p. 22.

complementary diopside, were formed at the contact of a 6- to 8-foot vein of felspar rock, mostly albite, with the Archaean marble into which it is intruded. As at Scawt Hill,[1] the complementary lime-silicate has not been removed from the scene of reaction, and this example also seems to illustrate the same point as the Scawt Hill occurrence, namely, the restricted potentiality of igneous magma to generate alkali types by assimilation. In the case of an acid quartz-bearing intrusive rock, with a potash-felspar-granite-pegmatite vein several feet thick, in contact with limestone, a contact zone less than a foot thick, composed of scapolite, diopside, felspar and calcite is produced. According to Dr. L. L. Fermor similar cases are common in the Chhindwara district of the Central Provinces.

**Calc-gneisses.**—The calc-gneiss is usually diopside-gneiss, and resembles similar rocks from the Archaean of Peninsular India. In some cases graphite is present. The silicate minerals in the calciphyres are commonly diopside, phlogopite, and forsterite. Lately Banerji [2] has found chrondrodite in the limestone of the Mogok Series.

**Calc-Granulites.**—The freshest exposures of calc-granulites near Mogok occur around the foot of Lone Spur. They are massive, fine-grained, light-coloured, granular rocks with a banded structure.

**Limestone and Associated Rocks.**—Very closely and intimately associated with the rocks of the basic and ultrabasic series are the metamorphosed limestones, which vary very widely both in texture and composition. As graphically described by Judd, "there are few more beautiful limestones than this rock of Mogok, with its delicate blue tint and brilliant cleavage of its twinned calcite crystals." Between the pure crystalline limestones, where the individual crystals of calcite grow up to the size of a man's fist, and the pyroxene-gneisses containing crystals of calcite and dolomite, every gradation can be traced and all the intermediate members can conveniently be grouped under the heads of cipolinos, calc-schists and calciphyres. The limestones, however, generally

[1] Tilley, C. E., "The Dolerite-Chalk Contact of Scawt Hill, Co. Antrim," *Mineralogical Mag.*, vol. xxii, 1931, pp. 439-467.

[2] *Rec. Geol. Surv. Ind.*, vol. lxvi, 1932, p. 93.

have a medium granular appearance, with flakes of graphite and phlogopite. They contain pseudomorphs after forsterite, colourless diopside, tremolite, sphene, pyrite, apatite, spinels of blue, black, red or pink shades and ruby. They carry varying amounts of dolomite.

**Origin of the Limestones.**—The origin of the corundums and spinels will be referred to at length later, though mention may here be made of the fact that the problem of the origin of the precious stones is intimately connected with the origin of the limestone itself, which is still an unsettled problem. Judd, as a result of the microscopic examination of thin sections of the limestones and associated rocks, arrived at the conclusion that the limestone had been formed by chemical processes, through the alteration of the unstable scapolite contained in the basic gneisses. La Touche was inclined to doubt this explanation of the formation of such enormous masses of practically pure calcite. He considered them of sedimentary origin, and thought that their field occurrence along particular zones in the gneiss, and also the presence of narrow bands of limestone in the gneiss itself, seemed to support his view. La Touche also regarded the graphite, associated with the limestone, to be of organic origin, since it is entirely absent from the gneiss and is present in the limestones only. He also referred to the gem-bearing limestones of the neighbourhood of Nanyaseik in the Kamaing Subdivision of the Myitkyina district. According to Bleeck[1] "every single specimen possesses the peculiarity of giving off an evil smell when struck with the hammer. This smell originates from organic matter, probably skatole." The author[2] has examined these limestones, and there is very little doubt that the gem-bearing limestones are simply the result of contact effects of the intrusion of granite, as in places they are seen to pass insensibly into normal sedimentary limestones, which sometimes bear *Fusulina elongata*, *Fenestella*, *Textularia* and various forms of *Globigerinidae*. Moreover, the practical continuity of the bands of coarsely crystalline limestone in a well-defined zone, more than 250 miles in length, is held by Loveman to be an almost con-

[1] *Rec. Geol. Surv. Ind.*, vol. xxxvi, 1908, pp. 164-170.

[2] *Rec. Geol. Surv. Ind.*, vol. lxii, 1929, p. 108.

clusive proof of their original organic origin. It is not improbable that the calc-gneisses have perhaps originated in the manner postulated by Judd, while the gem-bearing marble is the true metamorphosed representative of limestone originally of sedimentary origin.

**Grade of Metamorphism.**—According to Dr. L. L. Fermor,[1] one of the most interesting features of the rocks of the Mogok portion of the Stone Tract is that they exhibit a grade of metamorphism characteristic of the hypomorphic zone (Grubenmann's and Niggli's katamorphic zone), and that their analogues are found in the rocks of the Eastern Ghats of India (Vizagapatam, etc.), Ceylon and Tinnevelly. According to the same authority this is indicated at once by the fact that certain minerals are notably absent, the most important of them being epidote, green hornblende, staurolite, kyanite, chlorite, sericite and muscovite (except in a single case) and microcline. The presence of pyroxene wherever possible, the fact that the potash-felspar is either orthoclase or cryptoperthite, the fact that the calcareous rocks are devoid of quartz, and the common presence of scapolite, as well as of cordierite, spinel and sillimanite in certain of the rocks, all show strongly that the rocks of the Mogok area belong to a suite characteristic of the hypo-zone. Dr. Fermor goes on to state that the garnetiferous granulites are especially interesting in this respect, as the presence of sillimanite, combined with the facts that the felspars are cryptoperthitic and graphite is occasionally present, causes these granulites to approach in mineral composition the felspathic khondalites of Ceylon. Further, both the Eastern Ghats Province and Ceylon contain hypersthenic rocks assigned to the charnockite series. Though no undoubted charnockite has been yet found in the Mogok tract, rocks possessing great similarity are known to exist.

**Correlation.**—It has already been pointed out that there is a marked similarity between the pyroxene-granulites intercalated with the Archaean gneisses and the charnockite of South India. The charnockite has been found to be intrusive into the older gneisses of Peninsular India. Furthermore, the crystalline limestones, pyroxene- and scapolite-gneisses and granulites of

[1] *Op. cit. sup.*, vol. lxv, 1931, pp. 85-86.

the Mogok region bear a very close resemblance to the rocks of the Dharwar System of Peninsular India, especially to the crystalline limestones with the associated Dharwar rocks in the Chhindwara district of the Central Provinces. La Touche considered the characters and relations of the rocks in the two areas almost identical. In both districts occurs a series of crystalline limestones closely associated with quartz-pyroxene-gneisses and calciphyres forming lenticular bands embedded in biotite-gneisses, which latter, in the Chhindwara district, Dr. Fermor considered as being the most ancient rocks of the area. On that evidence La Touche concluded " that it seems probable therefore that the biotite-gneisses should be referred to one of the older divisions of the Archaean group, while the limestones and the associated pyroxene-gneisses, etc., may be considered to belong to the Huronian system, with which the Dharwars of India are correlated." However, until more detailed information is available La Touche considered it advisable to place these rocks in a single group for the present.

## II. MARTABAN SYSTEM.

The term Martaban System was first applied to denote the crystalline rocks which occur so extensively in the Martaban area, and which when petrologically considered are " undistinguishable from the ordinary gneissose rocks of Bengal." Later work has indicated that this system includes two distinct types of crystalline rocks of two different ages. One of them belongs to the Archaean period, while the other, which is considered to be intrusive into the former, is probably of post-Permian age.

Petrologically little is known about this system, and the extent of each of the two aforementioned groups has not been worked out. They are known to be crystalline rocks composed of gneisses and schists of probably diverse origin. One variety of this rock, which occurs in the Dawna ranges, is the Dawna gneiss, used extensively as road metal. It is a blue-grey, biotite-gneiss which is either coarse or fine-grained in texture. Mica- and talc-schists have also been noted in addition to the Dawna gneiss.

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# CHAPTER XII

## TAWNG-PENG SYSTEM

A WELL-DEFINED group of unfossiliferous rocks occupying a broad area of very broken hilly country between the Mogok gneisses in the Ruby Mines district and the fossiliferous rocks of the Northern Shan States has been called the Tawng-Peng System by La Touche, since the sub-State of that name is almost entirely composed of these rocks. It is separated from the succeeding formations by a marked unconformity on the western side. The rocks of the system have been divided into three groups, noted below, in descending order:

Bawdwin Volcanic Series,
Chaung Magyi Series,
Mica-Schists of Möng Lông with intrusions of granite.

### I. MICA-SCHISTS OF MÖNG LÔNG.

The valley of the Nam-pai in which the town of Möng Lông is situated, and the spurs of the ranges to the south of it, are built of a broad band of schists known as the Mica-Schists of Möng Lông. The schists appear to be cut off from the adjacent gneisses by the continuation of a north-south fault, which coincides in part with the lower reaches of the Nam-pai at the place where its bed is covered by these schists. Their exact distribution is not fully known. Furthermore, these schists and the overlying rocks belonging to the Chaung Magyi Series weather in almost the same manner and give rise to the same kind of soil; besides, there appears to be a gradual passage between these schists and the overlying deposits.

The general strike of these schists is nearly east-west, though variation from this direction occurs, probably due to the intrusion of dykes and bosses of granite.

**Lithology.**—The rock is an ordinary biotite-schist, composed mainly of granular quartz and biotite, the latter occurring in large quantity in lath-shaped crystals, arranged parallel to the foliation planes, and a little plagioclase felspar. Minute crystals of apatite with some tourmaline (?) are present as accessories. The schists are traversed by a number of veins of milky quartz, which are of varying dimensions and which ramify through them in all directions. On account of the easy weathering of the schist, the quartz veins stand out as prominent knolls on the ridges and slopes of the hills, and in many cases the distribution of the schists has to be followed with the help of the quartz veins alone. Though not limited to any particular zone the veins are numerous near the junction of the granite and the schists.

**Intrusive Granite.**—Between the Mogok gneisses and the Möng Lông mica-schists are several tongues and dykes of intrusive granite, which are well exposed on the cart road from Mogok to Möng Lông, between the villages of Yaunggwin and Legyi. The rock is a coarse granite, consisting mainly of orthoclase felspar with some interstitial quartz and a good deal of tourmaline. Fibrolite, apatite and garnet occur as accessory constituents. As mentioned below, the rainwash derived from these granites covering the lower slopes of the hills in the neighbourhood of Na-yuk, about 11 miles to the south-east of Mogok, has been extensively worked for tourmaline (rubellite).

## II. CHAUNG MAGYI SERIES.

Of the three sub-divisions of the Tawng-Peng System the Chaung Magyi Series is stratigraphically the most important. It is probably the oldest sedimentary formation of Burma, and overlies the Möng Lông Mica-schists. As noted above, there is a gradual transition between the mica-schists and the rocks of this series. When the mica-schists are traced in a southerly direction from the Nam-pai Valley to the Shan plateau, the well-foliated schists give place to either a series of quartzites, generally of a red or brown colour, occasionally containing a little felspar, when they may be called greywackes; or of slaty shales, generally dark blue in colour, constituting the Chaung

Magyi Series. Conglomerates are conspicuous by their absence, and no sign of any stratigraphical break has been observed. The series is again marked by the entire absence of any trace of lime, while the overlying deposits are of a calcareous nature. Although the rocks of this series are well suited for the preservation of fossils, the closest search has failed to reveal any trace of organisms. The Chaung Magyi rocks may well be said to form the floor or the basement on which the subsequent fossiliferous deposits were laid.

**Exposures.**—Exposures of this series are seen mostly in new road cuttings or in the beds of streams ; but seldom on hill slopes, on account of the thick covering of the overburden and dense growth of vegetation. It is generally difficult to obtain a continuous section for the purpose of ascertaining its thickness or for working out the succession of rocks, as they are faulted and folded on a large scale. Moreover, the beds, when exposed to the atmosphere for some length of time, become rotten and decomposed, and are not easily distinguishable from the overlying formations.

**Lithology.**—This is mainly an argillaceous series, and consists of soft, well-foliated, slaty shales, phyllites and greywackes with subordinate sandy horizons. The slaty shales are greyish, greenish, bluish, or purplish in colour, and are often bleached ; they contain much vein quartz and sometimes weather to soft mudstones. The phyllites, when examined in thin sections under the microscope, show the presence of graphitic matter and fine quartz with numerous small flakes of a colourless sericitic mica, parallel to the cleavage of the rock, which is well developed. The quartzites, which are really the metamorphic representatives of sandstones, contain abundant irregular quartz grains, both large and small, together with much opaque, yellowish-brown ferruginous matter. To the north of Bawdwin sandy layers occur commonly in the midst of greenish slaty shales. Granitic and basic intrusions that occur in this series are described in detail in chapters XXVII and XXVIII on Igneous Activity. In the metamorphic aureole, bordering the granite, the Chaung Magyis are converted into hard quartzites, sometimes felspathic, and micaceous slates and phyllites.

**Distribution.**—The rocks of this series formed the floor on

which the overlying fossiliferous deposits accumulated. Consequently, it is only in those places where the overlying rocks have been removed that the rocks of this series are seen. On the west of the Shan Plateau they occupy a narrow zone below the precipitous scarps of limestone overlooking the plains of the Irrawaddy, and extend southwards to the point where the Chaung Magyi or Madeya river turns westwards. The western boundary of this belt is marked by a fault, thus bringing the series against not only the Archaean gneisses in the north, but also the Plateau Limestone and other Palaeozoic deposits in the south. In the whole of this zone the strike of the quartzites and slates is north-south, parallel to that of the gneisses on the west bank of the Irrawaddy. On the east they appear among the hilly ranges of the Shan plateau and the Salween, forming large inliers among younger rocks, wherever the latter have been removed by denudation ; their boundary is therefore very irregular and highly indented. As seen in the section across the centre of the Loi-len range the slates and quartzites appear from beneath the lower Palaeozoic rocks at the foot of the range, immediately to the north of Man-Se in the Namma coalfield, and widen out rapidly eastwards, forming the whole of the southern slopes for a distance of about 18 miles, beyond which they are covered up by overlying limestones (see Fig. 14). Along the foot of the range they are cut off by a fault of considerable throw.

To the south-east of Loi Ling these rocks occupy an irregular area, the structure of which is by no means easy to unravel; but it may be described briefly as a series of domes, the axes of which run directly due north and south. As seen in the section across the ranges east of Mong Yai these have been broken up by a complicated set of great faults, whereby huge wedge-shaped masses of the overlying strata have been let down among the older rocks, some of the faults striking in a direction almost parallel to the axes of the domes, while others cut directly across them. The quartzites and slates occupy the cores of the domes and rise into lofty ridges and peaks, attaining altitudes of between 4,000 and 6,000 feet above sea-level.

Another inlier of these rocks exists to the south of the plateau in the sub-State of Mong Tung, forming a conspicuous moun-

tain mass, rising in Loi Pan to a height of 6,693 feet above sea-level and extending into the south in the Southern Shan States. Here the slates and quartzites of the Chaung Magyi Series rise above the plateau from the surrounding plateau limestone. Farther south, in the latitude of Mong Tung, the quartzites are replaced by grits and sandstones and the slates by unaltered shales. This variation is believed by La Touche to be a local characteristic, and the metamorphism of the rocks in the north is considered to have been brought about by the intrusion of large dykes of granite.

**Southern Representatives.**—In the Yamethin district slates and quartzites, believed by Dr. Cotter [1] to be identical with the Chaung Magyi Series, occur near the edge of the hills, and are exposed both west of Yinmabin railway station and also in the neighbourhood of Nankwe village. The igneous rocks, which are intrusive into the local representative of the series under description, are mainly gneissose granites, with subordinate bands of intermediate intrusives, including felsite, porphyry and augite-lamprophyre. The belt of Chaung Magyi rocks and intrusive granites occupies the outer margin of the hills.

**Northern Extensions.**—Loveman, while mapping the area between the Northern Shan States and Yunnan, found rocks similar to those described above, and consisting of slaty shales, phyllites and quartzites, severely folded and with a rapidly varying strike. According to him the band of rocks of the Kao-liang Series mapped by Coggin Brown in Yunnan, just east of the Shweli river in lat. 24° 40′, is undoubtedly a direct continuation of the Chaung Magyi Series of the Northern Shan States.

Farther north, on the North-eastern frontier of Burma, similar greyish slaty shales [2] crop out near mile 64 on the Htawgaw road. These, with several small intrusions of granite-gneiss, build the core of the Pyehpat range, about 7,000 feet above sea-level, where it is crossed by the road. They have been called the Pyehpat shales. On the western side of the range they are folded, but on the eastern side they show a general

[1] *Rec. Geol. Surv. Ind.*, vol. lviii, 1925, p. 73.
[2] *Rec. Geol. Surv. Ind.*, vol. lxvi, 1925, p. 89.

westerly dip. Similar shales crop out again near mile 120 on the Hpimaw road, and continue as far as the Inspection Bungalow at Hpimaw (25° 0′, 98° 38′). They were also traced farther south on the Fenshuiling Pass road, where they are overlain unconformably by limestone, highly brecciated in places and probably of the same age as the Plateau Limestone of the Northern Shan States.

**Tectonics.**—It has been pointed out above that the difficulty in tracing outcrops of the Chaung Magyi Series is due in part to the complicated structure of the deposits. The strike of the series is seldom constant, and is frequently subject to abrupt changes. It is believed that the changes of strike may be due to distinct and successive periods of earth movements. According to La Touche there is ample evidence that the prefossiliferous rocks were folded and dislocated by forces acting from different directions at successive periods before the deposition of the overlying strata. The final thrust, which has affected all the rocks of earlier dates than the Tertiary, seems to have come from the south-east or perhaps the east, since the direction of folds and fractures that traverse the Namyau Series of Jurassic age is from N.N.E.–S.S.W.

It has also been mentioned that the Chaung Magyi Series occurs as inliers in younger strata. Referring to this La Touche states: "Indeed, it seems not improbable that these ancient rocks did form islands or shoals in the midst of the Palaeozoic ocean, for the rocks that were deposited upon them thin out in a remarkable manner as they approach the inliers; the lowest fossiliferous rocks forming a very narrow ribbon separating the Plateau Limestone from the slaty series, or in many places not appearing at the surface at all, the limestone overlapping them and resting directly upon the slates and quartzites."

**Age and Correlation.**—On account of its unfossiliferous nature the age of the Chaung Magyi Series has remained unsettled; the available evidence being its stratigraphical position and lithological characters. As regards its stratigraphical position, it belongs to a group of rocks which were highly folded and exposed to the agents of denudation, prior to the deposition of the succeeding fossiliferous deposits. The immediately overlying strata are the graptolite-bearing beds of Ordovician age.

As regards their correlation, La Touche was struck with their great similarity to the Shillong Series in the Khasi Hills of Assam. Both series are made up of slaty shales and quartzites. The Dharwar age of the Shillong Series is disputed by La Touche, and he concluded that it corresponds to some portion of the Purana group. The Chaung Magyi Series has, in addition, been compared to the Hu-t'o System of Northern Shan-si in China, the age of which is surmised to be pre-Cambrian. Until more detailed information is forthcoming nothing can be said with certainty.

The Chaung Magyi Series is overlain by the Bawdwin volcanic rocks, the description of which is included in the chapters on Igneous Activity.

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# CHAPTER XIII

## ORDOVICIAN SYSTEM

THE fossiliferous rocks overlying the Tawng-Peng System belong to the Ordovician System, and have been classified as follows, in descending order:

(Nyaungbaw Limestone.)
Hwe-Mawng Purple Shales.
Upper Naungkangyi Stage.
Lower Naungkangyi Stage.
(Ngwetaung Sandstones.)

This sequence is not universally present and some of the beds have an extremely local distribution, especially those within brackets. It is quite probable that some of them belong to one and the same series; but in the present state of our knowledge it seems desirable to give them separate names.

### I. Ngwetaung Sandstones.

This stage is developed only very locally. The relationships of the sandstones with the underlying Chaung Magyi Series are not distinct. They are faulted on the west against Devonian limestones. One of the conspicuous places where these sandstones outcrop is the Ngwetaung hill, which rises to a height of 3,403 feet from the foothills due east of Mandalay; the crest and western slopes of this hill are composed of the rocks of this stage.

Fine- and coarse-grained brown sandstones, which are in places highly calcareous, with occasional lenticular bands of limestone, constitute this stage. Fossils are very rare; the only ones that have been discovered being a few scattered remains of crinoid or cystidean stems and a few ill-preserved specimens of *Orthis* (*O.* cf. *testudinaria*).

## II. Pangyun Beds.

The term "Banyan Beds" was originally proposed by Maclaren in an unpublished paper to designate a series of "fairly thin-bedded rocks made up of red and white sandstones, chocolate micaceous shales and quartzites with subordinate dark shaly beds and occasional conglomerates." This term was subsequently changed into "Pangyun Beds" by Dr. Coggin Brown after the Nam Pangyun, in the valley of which the best continuous exposures of these beds are seen.

**Stratigraphic Position and Age.**—The Pangyun beds are in absolute conformity with the underlying Bawdwin volcanic series and with the overlying fossiliferous Lower Naungkangyi beds. Their age is either Lower Ordovician or Cambrian, but as they are unfossiliferous this cannot be decided with certainty. In the neighbourhood of Bawdwin they have a wide distribution and form an important stratigraphic horizon.

**Lithology.**—This group consists of purple shales, thinly bedded sandstones, hard, greyish-green, chocolate-coloured micaceous quartzites and fine-grained speckled grit. The quartzites are variously mottled and are well jointed, and in some cases are broken up into small cleavage fragments; they are also marked with horizontal slickensided grooves, apparently produced by lateral shearing movements. In some places they are spotted with brown limonite. A close alternation of quartzites and shaly slates is also observed in a few places. In places bands of conglomerate consisting of rolled pebbles of quartzite and rhyolite and clear quartz pebbles derived from the rhyolites occur. All the different layers of the Pangyun beds possess moderate dips, and there is a highly prevalent easterly dip up the Nam Pangyun valley. In the neighbourhood of Bawdwin the rocks are highly distorted and fractured as a result of the Bawdwin overthrust.

## III. Lower Naungkangyi Stage.

The Lower Naungkangyi beds occur as detached outcrops at various places on the Shan plateau, and good sections are seen in the Gokteik gorge and in the valley of the Nam Pangyun. In

almost every exposure there is a slight variation in the lithology of the rocks, as a result of which the correlation of the different outcrops has been rendered very difficult.

**Lithology.**—In general, the Lower Naungkangyi beds are composed of variegated sandy marls, with interbedded bands of crystalline limestone. It is probable that the marly beds were originally calcareous, though they may now contain no trace of lime, and that their present condition is the result of the leaching out of the calcareous matter by weathering, for they are sometimes found to merge into solid limestone when excavated to a sufficient depth. The limestones associated with the Lower Naungkangyi beds are composed of an aggregate of somewhat coarsely crystalline grains of calcite, and detached stem joints and ossicles of crinoids, or more probably of cystideans, which are visible in thin sections of the rock and sometimes on its weathered surface. They are distinguished from the overlying limestones of Devonian age by their coarse texture and absence of dolomite. The limestones so frequently observed in the western ranges of the plateau are entirely absent from the Lower Naungkangyi beds of the eastern ranges, and the latter consist of a homogeneous yellow or buff-coloured sandy marl of soft texture in which few well-preserved fossils occur.

**Thickness.**—Good sections of the Lower Naungkangyi beds (see Figs. 13, 14 and 15) are exposed in the Gokteik gorge above the valley of the Kyetmouk river, where, with the underlying Chaung Magyi Series, they form a line of cliffs. In almost all places the line of junction of the lower and upper stages is not clearly visible, and hence it is very difficult to estimate their thickness. Besides, it appears that the thickness varies from one locality to another.

**Fossils.**—The Lower Naungkangyi beds contain numerous fossils; but the most characteristic are the cystids, especially *Aristocystis*, a stemless form, which elsewhere has only been found in Bohemia. According to Dr. Bather it has not been recorded from America or from the Ordovician of either England or the Baltic Provinces. It is one of the peculiar fossils of the Ordovician period. The bryozoan, *Diplotrypa*, two species of which have been found at Sedaw, is typically Ordovician, and is of wide distribution in northern Europe. Similarly the brachiopod

*Schizotreta* occurs typically in the Ordovician of Russia. The important fossils that have been obtained include the following :

Cystidea : *Aristocystis dagon*, *Heliocrinus* (many species), *Caryocrinus* (many species).

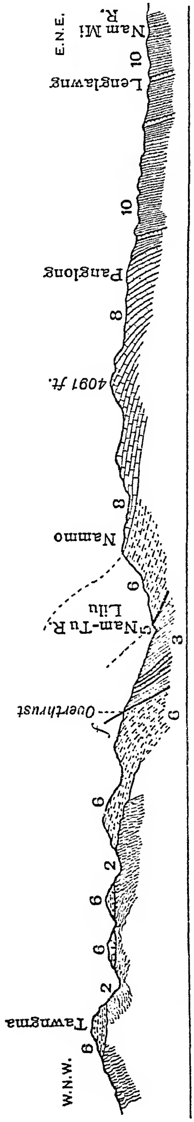
Bryozoa : *Rhinidictya* sp., *Diplotrypa sedavensis*, *Fistulipora* sp., *Phylloporina orientalis*.

Brachiopoda : *Rafinesquina imbrex* and *subdeltoidea*, *Schizotreta*, *Leptaena ledetensis*, *Plectambonites quinquecostata*, *Orthis irravadica*, *Orthis chaungzonensis*, *Orthis subcrateroides*.

Trilobites : *Calymene birmanica*, *Cheirurus dravidicus*, *Asaphus* cf. *devexus*, *Phacops* sp.

Particular fossils are as a rule confined to one particular locality, and according to Dr. Cowper Reed, there is more than one horizon in the Lower Naungkangyi stage, and the Sedaw limestone with its rich assemblage of cystidean fossils forms one of them. The Lower Naungkangyi beds correspond very closely with the Lower Ordovician rocks of the Baltic province.

**Mode of Deposition.**—Although there is a marked unconformity between the Lower Naungkangyi beds and the underlying Tawng Peng System, still there are no traces of conglomerates, or even




Horizontal & Vertical Scales 0 ½ 1 2 Miles

FIG. 13.—Section across the Nam-tu valley at Lilu, Northern Shan States.

10. Namyau Beds.
9. Naping Beds.
8. Plateau Limestone.
7. Zebyingyi Beds.
6. Namhsim Sandstone.
5. Panghsa-Pye Graptolite Band.
4. Hwe-Mawng Beds.
3. Naungkangyi Beds.
2. Chaung Magyi Series.
*f.* Faults.

of sandstones, coarse- or fine-grained, or anything else to indicate the presence of dry land in the immediate vicinity at the time of deposition. In La Touche's opinion "they appear to have been laid down in the open sea, perhaps in a sea of not very great, but uniform depth, judging from the homogeneous character of the deposits over wide areas. The presence of the Ngwetaung sandstones, and bands of limestone in the western portion of the area occupied by these deposits, and their greater thickness in that direction, seem to indicate that the coastline lay to the westward; and this conjecture appears to be the more probable, because no deposition seems to have taken place over the area occupied by the crystalline rocks to the north-west of the Shan States, throughout the whole of the Palaeozoic and Mesozoic periods."

## IV. Upper Naungkangyi Stage.

The Upper Naungkangyi beds, as regards their extent, constitute the most important formation next only to the Plateau Limestone, in the Shan States. On stratigraphical grounds La Touche considered it necessary to divide the Upper Naungkangyi stage into a lower and an upper division, and this was confirmed by study of the fossils. Like the Lower Naungkangyi stage two different lithological types, indicating probably two facies of deposition, can be distinguished in this stage. Broadly speaking, one variety of the Upper Naungkangyi rocks, which is mainly argillaceous, is confined to the beds of this stage exposed to the west of Lashio, while the second, consisting mainly of bright purple claystones, which are often highly calcareous, is the predominant type in the eastern ranges.

**Extent and Thickness.**—On the western side of the plateau the beds of this stage occupy a large area, extending northwards from a line drawn along the base of the hills north of Maymyo to the head of the Sedaw valley near Sakangyi. Within this area they occur as scattered outcrops, and with very high, sometimes even vertical, dips. This is due in part to the "creep" along the steep hillsides, to weathering out of the "cleavage lines," or to the general compression of these soft strata between the overlying and underlying hard rocks into minor

folds and contortions. La Touche estimates the thickness of these beds at 700 to 1,000 feet.

**Lithology (Western Area).**—This stage, in the western part of the plateau, consists of variegated argillaceous shales and claystonés often resembling lithomarge in texture. They range in colour from red through lavender, orange and various shades of yellow, to pure white. They exhibit strong evidence of having been subjected to considerable dynamic stresses: their original bedding planes have been obliterated as a result of the development of slaty cleavage probably by crushing; not infrequently a "slickensided" appearance is seen when they are broken. Furthermore, the distortion of the fossils confirms this. The shales are succeeded here by a narrow band of purple shales which is only a few feet in thickness, and yet very conspicuous by its colour and wide distribution.

**Fossils.**—According to La Touche the number of individual organisms living in the seas of this period must have been enormous, as one seldom breaks a small piece of rock without exposing at least the stem joint of a crinoid or a cystidean.

It is noteworthy that the fossils found at the various localities have only a very local distribution, and the fauna of one locality is never strictly comparable with that of another, but appears to depend entirely upon local conditions of environment. The brachiopods are mostly found in calcareous sandy beds, the cystideans and trilobites in argillaceous shales. Judging from the sandy texture of the brachiopod beds, La Touche came to the conclusion that these beds were deposited in the shallower portion of the sea, affected by strong currents. Such a mode of deposition might account for their lenticular character and local peculiarities of the fauna of these beds. The following list includes the important fossils found in the Upper Naungkangyi beds in the Northern Shan States:

**Cystidea**: *Heliocrinus* sp., *Caryocrinus* cf. *aurora*, *Echinoencrinus* cf. *angulosus*.

**Bryozoa**: *Phylloporina* sp., *Ceramopora* sp., *Rhopalonaria asiatica*, *Diplotrypa palinensis*.

**Brachiopoda**: *Lingula* cf. *attenuata*, *Orthis* (*Dalmanella*) *testudinaria* var. *shanensis*, *Orthis* (*Dinorthis*) *porcata* var.

*birmanica*, *Orthis calligramma*, *Strophomena* sp., *Rafinesquina subdeltoidea*, *Plectambonites sericea*, *Porambonites sinuatus*, *Clitambonites* cf. *squamata*.

Pelecypoda : *Shanina vlastoides*.

Gastropoda : *Hyolithes* (*Orthotheca*) *irravadicus*, *H.* (*O*) *loczyi*.

Cephalopoda : *Trocholites* sp.

Arthropoda : *Agnostus* cf. *glabratus*, *Ampyx* sp., *Harpes* sp., *Lichas* sp., *Illaenus liluensis*, *Calymene birmanica*, *Calymene* (*Pharostoma*) *liluensis*, *Cheirurus submitis*, *Holometopus wimani*, *Phacops* (*Pterygometopus*) *dagon*, *Pliomera* (*Encrinurella*) *ingsangensis*.

## V. Hwe-Mawng Purple Beds.

It is desirable to treat the Hwe-Mawng beds in conjunction with the Upper Naungkangyi stage, as they appear to represent the whole or part of this stage at least in the east of the plateau. The Upper Naungkangyi beds are covered at the top by a layer of purple clays which can be distinguished from the purple clays described above, by the absence of calcareous matter, by the possession of a kind of conchoidal fracture, by its tendency to become aggregated into nodular concretions, and by the absence of any well-defined bedding planes. On the west of the plateau they rest on the top of the variegated shales, while in the eastern ranges they lie directly on Lower Naungkangyi beds in the absence of the variegated shales. Thus these shales, which have been termed the Hwe-Maung beds, seem to correspond in age with the lower shaly horizons of the Upper Naungkangyi beds of the western area, since they contain similar fossils, and especially the trilobite *Pliomera ingsangensis*. This fossil is freely distributed throughout and is common near the base of the formation.

All the beds of this stage which occur to the east of the Gokteik gorge, are also argillaceous below, but are marked at the top by the occurrence of a persistent narrow band of dark purple shales, which are calcareous enough to be described as impure limestone. This has often a misleading schistose appearance, and the calcareous matter occurring in the form of lenticular " eyes " imparts an " augen " structure. The lower

portion, which is argillaceous, is full of crinoid stems and cystidean plates, with a few trilobites, all in a somewhat bad state of preservation. Along the crest of the Loi-len range they have been highly crushed, and in some places, as on the pass near Loi-len village, the pressure has been so great that the beds resemble a schist rather than a shale.

Fossils from the Hwe-Mawng purple shale include the following as well as *Orthis* (*O. testudinaria* and *O. subcrateroides*), *Plectambonites sericea*, *Shanina vlastoides*, *Hyolithes loczyi*, *Pliomera* (*Encrinurella*) *ingsangensis*, which are species occurring also in the Naungkangyi beds :

**Bryozoa** : *Ptilodictya* sp.

**Brachiopoda** : *Stropheodonta* aff. *corrugatella*, *Orthis* (*Dalmanella*) sp., *Christiania tenuicincta*.

**Mollusca** : *Platyceras yulei*, *Trocholites* cf. *remelei*, *Hyolithes clivei*.

**Arthropoda** : *Ogygites birmanicus*, *Ptychopyge thebawi*, *Megalaspis* aff. *hyorhina*, *Dionide hybrida*, *Ampyx rostratus*, *Illaenus* sp., *Holometopus orientalis*, *Pliomera* (*Encrinurella*), *ingsangensis*.

The list of fossils from the Hwe-Mawng beds of the eastern area is given above separately, since according to Dr. Cowper Reed it is uncertain to what extent the Hwe-Mawng Purple Shales are equivalent to the Upper Naungkangyi stage of the western area. The same authority concludes that the connection of the Naungkangyi beds with the Hwe-Mawng beds is shown by their possession in common of certain species, especially *Pliomera* (*Encrinurella*) *ingsangensis* ; but the presence in the Hwe-Mawng beds of a large number of peculiar trilobites, especially Asaphids, and the generally distinct assemblage of fossils which they contain, suggests a slightly different age. The presence of *Ogygites*, *Megalaspis*, *Ampyx*, etc., may indicate an Upper Ordovician age ; but from the palaeontological evidence alone it is difficult to say whether the beds should be regarded as older or younger than the Naungkangyi series or any portion of them.

**Age.**—In the present state of our knowledge the age of the Naungkangyi beds only as a whole can be established satisfactorily.

The very local distribution of the fauna precludes the possibility of correlating the various beds exposed at different places. In the opinion of Dr. Cowper Reed, who described the fossils from this area, there is decided evidence of their reference to part of the Ordovician, such species as *Graptodictya birmanica*, *Plectambonites* aff. *llandeiloensis*, *Porambonites sinuatus*, *Ampyx* aff. *macallumi*, *Harpes* aff. *flanagani*, *Holometopus wimani*, *Calymene birmanica*, and *Pterygometopus dagon*, etc., showing affinities with the Llandeilo and Caradoc (or Bala) groups of Europe. *Pterygometopus* is specially characteristic as a sub-genus in this respect.

**Affinities of the Fauna.**—The most remarkable point about the fauna of the Ordovician of Burma is that it is more closely allied to that of northern Europe, especially to that of the Baltic provinces, than it is to that of the Central Himalayas. The Ordovician of the Himalaya in Spiti and Kumaon contains no cystids and extremely few trilobites, and its fauna generally resembles that of the American beds of the same age. On the other hand the Naungkangyi beds are characterised by an extraordinary profusion of cystideans, which according to La Touche are "so universally distributed throughout the rocks that almost every fragment that one breaks open contains portions of detached plates. They must have literally swarmed in the seas of that period." Similarly, five species of corals are described from the Himalaya, but in Burma they are conspicuous by their absence or rarity. Again, Cowper Reed has described 27 species of lamellibranchs and gastropods, which are groups hardly represented in Burma at all. It would not be rash to conclude, therefore, that in Ordovician times the Arctic Sea, which covered what is now northern Europe, extended into Burma as far south as lat. 21° N., and was cut off from the sea then occupying the Central Himalayas. The former sea then covered central and north-eastern China also, but its southern limits are so far unknown.

According to Coggin Brown the Pu-pjao beds of Yunnan are identical with the Naungkangyi formation of the Northern Shan States. A rich fauna consisting of cystideans, trilobites and graptolites, including *Didymograptus*, has been obtained. Similar beds also occur in eastern and north-eastern China.

### VI. Nyaungbaw Limestones.

Between Mandalay and Maymyo a thin band of limestone, which eventually merges into the Plateau Limestone, occurs within a mile of Nyaungbaw rest house. The beds contain the characteristic fossil, *Camarocrinus asiaticus*. Dr. Noetling first included these limestones with the underlying Mandalay Limestone, and designated them as the Pyintha Limestone. La Touche, however, discovered that the two limestones were of different ages, and termed the limestones with *Camarocrinus asiaticus* the Nyaungbaw Limestones.

**Lithology.**—These limestones are, for the most part, red or chocolate brown in colour, passing into grey or bright blue and sometimes purple rocks. They are interbedded with bands of red clay, and the limestones themselves usually contain a large amount of argillaceous matter, in which case they present a peculiar lenticular structure like that of the German " Knollenkalk " or " Netzkalk."

**Fossils.**—Besides *Camarocrinus asiaticus*, *Lingula quadrata*, *Orthis irravadica*, and *Plectambonites repanda* have been found in them.

**Age.**—Their stratigraphical position and the presence of *C. asiaticus* indicates that the Nyaungbaw limestones are very closely connected in age with the underlying Naungkangyi beds of Lower Ordovician age, rather than with the overlying Zebyingyi beds of Silurian age from which they are separated by an unconformity. These beds really form the uppermost division of the Ordovician. *C. asiaticus* also occurs in Yunnan.

### VII. Ordovician of the Southern Shan States—Mawsön Series.

In the Southern Shan States rocks of Ordovician age have been classified by Coggin Brown into (1) Mawsön Series, (2) Orthoceras Beds, and (3) Pindaya Beds. The Mawsön Series forms the eastern part of the Mawsön highlands, which is a broad anticlinal fold, complicated by local bending and perhaps by central faulting, and the strata on the east differ from those on the west. In the former case the " augened," argillaceous limestones and calcareous shales overlying the mud-

stones, shales and sandy shales give rise to well-marked escarpments, which are wanting on the west, where thick limestone horizons are separated by a few strongly marked and persistent beds of sediments. The beds are not very rich in fossils, but occasionally on weathered surfaces they display sections of brachiopods together with *Orthoceras* or *Actinoceras* sp. At Bawzaing, cephalopod remains determined by Dr. Cowper Reed as probably either *Cycloceras* sp. or *Sphyradoceras* sp., were obtained, while two miles farther south abundant specimens of *Orthis emancipata*, a rare example of *Lophospira* sp., and fragments of a large trilobite, which seems to be an Asaphid, besides *Ogygites*, *Pliomera*, *Cyrtolites*, *Helicotoma*, were collected. In the opinion of Dr. Cowper Reed this evidence is enough to stamp the rocks as probably Upper Ordovician with a new fauna of their own. The series continues south, and according to Dr. Coggin Brown probably forms most, if not the whole, of the He-ho range.

The lead-ore deposits of Mawsön occur very largely within these rocks. Rocks of Ordovician age are met also on the top of the Taunggyi ridge and to the north of Hopong. They also form part of the Taunggyi range between the town itself and the Yaunghwe valley. Fossils [1] collected from these rocks include cystideans, bryozoa, trilobites and brachiopods. Several species of *Orthis* very similar to those found in the Naungkangyi series of the Northern Shan States, are present.

### VIII. Orthoceras Beds.

The Orthoceras beds form the great part of the western limb of the Mawsön anticlinal fold mentioned above. They consist of hard, flaggy, pink, purple or reddish argillaceous limestones and calcareous shales with a peculiar phacoidal structure. They usually contain large crinoid stems and numerous specimens of *Orthoceras* or similar genera. They are best developed in the valley to the east of Pawmye and on the flanks of the peak, 4,613 feet high, to the north-east of Naungkaya. According to Dr. Coggin Brown they seem to be underlain in the former locality by yellow sandy mudstones with

[1] These are now under examination by Dr. Cowper Reed.

badly-preserved fossils recalling those of the Naungkangyi series.

On the eastern limb of the anticline at Mawsön, so far as it has been examined, these beds are replaced by stronger, purer limestone bands with interbedded sandy horizons; but a short distance farther north near Kanaingwaing in Lawksawk State, identical rocks appear. They crop out also near Taungni and Pon on the higher ground separating the head of the Inle valley from the Kunlon plain.

The Orthoceras beds occurring to the north-east of Pindaya contain a greater proportion of shales than is found in the type locality described above. Specimens of *Orthoceras* sp. or allied genera are abundant in these beds.

## IX. Pindaya Beds.

Dr. Coggin Brown gave the name of Pindaya Beds to the rocks that build the Pindaya range between the bands of Permo-Carboniferous limestone, which forms the frontal scarp overlooking the Pindaya valley on the west, and the crest of the range, as far as they have been traversed to about long. 96° 40′. The beds are composed of calcareous shales, slates and thin bands of argillaceous limestone interbedded with sandy mud- and siltstones. In the southern portion of the range, about Poila and Yeosin, the shales, slates and mudstones are more frequent than in the northern portion between Pindaya and Zawgyi. In both parts, however, there is a marked development of thick limestone bands, generally a hard, massive bluish-grey, calcite-veined rock, often with patches and seams of argillaceous and marly material. They have given rise to the intricate system of small cauldron valleys which are very numerous on its surface.

The examination by Dr. Cowper Reed of part of the fauna from the Yeosin locality, which includes the following fossils, has made their correlation probable with some part of the Lower Naungkangyi of the Northern Shan States, as several of the species seem identical :

*Orthis* spp., *Ptychoglyptus shanensis*, *Yeosinella consignata*, *Leptelloidea yeosinensis*, *Rhindictya* cf. *nitidula* and *Caryocrinus* spp.

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# CHAPTER XIV

## SILURIAN SYSTEM

THERE are few places in Asia where a complete succession of older Palaeozoic deposits exists; in India beds of this age occur in the not easily accessible northern or Tibetan zone of the Himalayas. But, fortunately for Burma, there is within easy reach a whole series of richly fossiliferous Silurian deposits of this period with their rich faunas, and, what is more, the basal beds of the Silurian system contain a definite fauna of undoubted Llandovery age and typical graptolite zones have been established.

**Sub-divisions.**—The Silurian system has been divided as follows in descending order:

| | |
|---|---|
| Zebingyi beds.<br>Upper Namshim or Kônghsá Marls.<br>Lower Namshim Sandstones. | Upper Silurian. |
| Panghsa-pye graptolite band.<br>Trilobite band. | Llandovery Series. |

### I. Panghsa-pye Graptolite Band.

Good exposures of this stage, which is but restricted in distribution and very limited in thickness, are found at Panghsa-pye village in the Nam-Tu valley, about eight miles to the north-west of Hsipaw, where it is represented by a graptolite band with a trilobite band lying underneath. The beds of this stage overlie without a break the Hwe-Mawng purple shales or the Upper Naungkangyi beds and form an important stratigraphical horizon.

**Lithology.**—This stage consists of fine white shales, of no great thickness, probably not more than 50 feet, and is full of

graptolites. In some localities a yellow sandy shale bed with trilobites underlies it. Sometimes the graptolites occur in black carbonaceous shales. These are very soft and are easily susceptible to the influence of weathering agents, and hence very often are hidden beneath talus débris.

**Fossils.**—The following list includes the more important fossils found in this stage :

Hydrozoa : *Diplograptus* (*Orthograptus*) *vesiculosus*, *Diplograptus* (*Mesograptus*) *modestus*, *Diplograptus* (*Glyptograptus*) cf. *persculptus*, *Climacograptus medius*, *Climacograptus tornquisti*, *Climacograptus rectangularis*, *Monograptus tenuis*, *Monograptus gregarius*, *Monograptus cyphus* var. *minor*, *Monograptus concinnus*, *Cyrtograptus* sp., *Rastrites peregrinus*.

Anthozoa : *Palaeocyclus ? haimei.*

Brachiopoda : *Pholidops implicata*, *Orthis* (*Dalmanella*) *elegantula*, *O. mansuyi*, *Stropheodonta mcmahoni*, *Stropheodonta feddeni*, *Plectambonites* sp.

Mollusca : *Holopea* sp.

Arthropoda : *Phacops hastingsi*, *Acidaspis shanensis*, *Bollia alexandri*, *Beyrichia* sp., *Turrilepas* sp.

These fossils clearly indicate a Llandovery age for the Panghsa-pye stage, which forms the lowest division of the Silurian in the Northern Shan States.

**Distribution.**—Besides the clear section of the Graptolite Band at Panghsa-pye, referred to above, it also occurs in the valley of the Nam-Tu at several places; well-preserved graptolites occur also in large numbers at the village of Ngai-tao, on the spur above Ta-pangtawng. The most important form found here is *Monograptus gregarius*, the zone fossil of the upper division of the Lower Birkhill shales. Farther north Dr. J. M. Maclaren found graptolites on the Nam Pangyun, about a mile above its conflux with the Nam-Tu, on the way to the Bawdwin silver mines. Here they occur in black carbonaceous sandy shale and are very ill-preserved.

The Graptolite Band also occurs in the hill ranges east of the plateau, resting upon the purple Hwe-Mawng beds. In the Loi-len range, east of Lashio, it was found on the southern

slope of the ridge, about two and a half miles E.N.E. of the village of Pangmo. At this locality the graptolites occur not only at the top of the purple beds but also in some white shales interbedded with the latter. A species of *Climacograptus* is the most common form found here.

About a mile south by east of Ping-hsai, in the gorge of the southern branch of the Nam-hen, graptolites occur in large numbers, but in highly carbonaceous, sandy shales, similar to those on the Nam Pangyun, with lenticular bands of coaly material. According to Miss Elles, the fossils constitute a characteristic assemblage from the upper part of the zone of *Orthograptus vesiculosus*, that is to say, they are almost of the same age as those of Panghsa-pye.

## II. Namhsim Stage.

Overlying unconformably the Hwe-Mawng purple shales and the older deposits there occurs a group of sandstones and marls which at first were taken as belonging to one stage. Palaeontological evidence showed that they really belong to two different stages ; later, stratigraphical evidence also proved that the marly beds, which were at first considered to be of limited distribution, had a much wider distribution, and that they could be separated from the sandstones. Consequently the Namhsim beds have been divided into upper and lower stages, similar to those of the underlying Naungkangyi beds.

### Lower Namhsim Stage.

**Distribution.**—The Lower Namhsim stage consists of sandstones, which give rise, on account of their resistance to weathering, to high and hilly ground ; this will be more readily understood when it is borne in mind that the underlying and overlying rocks, which are soft shales and marls respectively, are easily worn away. Not uncommonly the sandstones form well-marked and precipitous scarps. On the eastern side of the plateau they occur as long bands between the uppermost Ordovician beds and the Plateau Limestone ; their junction with the latter is generally marked by long faults. On the

western side of the plateau they run as a long, north-south band in the Plateau Limestone, enclosing as inliers irregular and rounded outcrops of the Naungkangyi and Hwe-Mawng purple beds. Along the northern edge of the plateau they appear as outliers on the Chaung Magyi rocks, and are not seen below the overlying Plateau Limestone, probably as a result of faulting or due to an overlap by the limestones.

Commencing from the west, the first locality where these beds are found is the crest of the Memauk spur, overlooking the valley of the Chaung Magyi at Aunglôk. Here the base of the Namhsim stage is formed of very coarse conglomerates, in which boulders and pebbles of the Chaung Magyi quartzites together with those of the rocks of the Mogok Series predominate. The conglomerates pass upwards into a series of rather coarse-grained, blue and purple, felspathic grits and sandstones.

The next outcrop of the Namhsim sandstones is to be seen along the northern edge of the plateau, between Kalagwé and the valley of the Nam-panhsé at Pa-mon. Here they rest on the Chaung Magyi rocks, but not underneath the limestone of the plateau, which may be due to faulting along the base of the hills, or it may be caused by an overlap of the limestones.

The lower Namhsims are again well developed on the right bank of the Nam-Tang, where they form precipitous cliffs, several hundred feet high, overhanging the river. From Namsaw eastwards the sandstones gradually thicken out and occupy a broad area as far as the valley of the Nam-Tu, north of Hsipaw. They extend up to and beyond Kiohsio, to the north of which village they form a line of picturesque pine-clad cliffs. Here, again, they overlap the Naungkangyi beds, and their limits can be distinguished by the lines of cliffs that they form overhanging the more gentle slopes of the softer schistose and slaty beds of the underlying Chaung Magyi Series. The boundary with the older rocks is deeply eroded, and exceedingly sinuous on account of the extremely deep, narrow ravines by which the whole of the State of Tawng-Peng is intersected. The outer boundary, as at Memauk, is characterised at the base by the development of conglomerates and grits, while they are absent from the inner boundary; and here

they rest with apparent conformity upon the graptolite beds beneath them.

**Lithology.**—The Lower Namhsim stage is essentially an arenaceous series; the sandstones are either coarse in texture or fine-grained and compact, hard and splintery. Occasionally their boundary with the older rocks is marked by beds of coarse conglomerates, consisting of water-worn pebbles and boulders of the Chaung Magyi quartzites. In those places where the conglomerates do not occur, the sandstones are usually coarse-grained, and for some distance up from their base are strongly felspathic and usually of a bluish-grey or purple colour. These gradually become less felspathic, passing into fine-grained brown sandstones, with layers of hard, white, very fine-grained, quartzose sandstones. Their total thickness according to La Touche is at least 2,000 feet.

**Fossils.**—The following species represent the important fossils found in the Lower Namhsims:

**Brachiopoda**: *Mimulus aunglokensis*, *Orthis* sp.

**Mollusca**: *Orthonota* (?) *spectabilis*, *Pycnomphalus* sp., *Orthoceras* aff. *tenuiannulatum*.

**Arthropoda**: *Proetus* sp., *Encrinurus konghsaensis*, *Calymene blumenbachi*, *Cheirurus* cf. *bimucronatus*, *Phacops* (*Dalmanites*) *longicaudatus*, *Illaenus namhsimensis*.

**Tectonics.**—A close examination of the section exposed in the valley of the Nam-Tu, in the neighbourhood of Lilu, (see Fig. 13) reveals an overthrust which has brought the Naungkangyi beds to rest over the Lower Namhsim sandstones. Broadly speaking, the structure indicated is as follows: the Namhsim sandstones appear to overlap the Naungkangyi beds: these were subsequently distorted by an overthrust fold or fault parallel to the Nam-Tu near Lilu, the beds having given way along the comparatively soft layers of the Naungkangyi shales, under the stress of an impulse acting from the east, and been driven up over the hard sandstone strata. The cause of such a dislocation having taken place along this particular line is perhaps to be found in the existence, only a short distance to the west, of the unyielding mass of the older Chaung Magyi rocks, forming the old land area of Tawng-Peng. The fault

western side of the plateau they run as a long, north-south band in the Plateau Limestone, enclosing as inliers irregular and rounded outcrops of the Naungkangyi and Hwe-Mawng purple beds. Along the northern edge of the plateau they appear as outliers on the Chaung Magyi rocks, and are not seen below the overlying Plateau Limestone, probably as a result of faulting or due to an overlap by the limestones.

Commencing from the west, the first locality where these beds are found is the crest of the Memauk spur, overlooking the valley of the Chaung Magyi at Aunglôk. Here the base of the Namhsim stage is formed of very coarse conglomerates, in which boulders and pebbles of the Chaung Magyi quartzites together with those of the rocks of the Mogok Series predominate. The conglomerates pass upwards into a series of rather coarse-grained, blue and purple, felspathic grits and sandstones.

The next outcrop of the Namhsim sandstones is to be seen along the northern edge of the plateau, between Kalagwé and the valley of the Nam-panhsé at Pa-mon. Here they rest on the Chaung Magyi rocks, but not underneath the limestone of the plateau, which may be due to faulting along the base of the hills, or it may be caused by an overlap of the limestones.

The lower Namhsims are again well developed on the right bank of the Nam-Tang, where they form precipitous cliffs, several hundred feet high, overhanging the river. From Namsaw eastwards the sandstones gradually thicken out and occupy a broad area as far as the valley of the Nam-Tu, north of Hsipaw. They extend up to and beyond Kiohsio, to the north of which village they form a line of picturesque pine-clad cliffs. Here, again, they overlap the Naungkangyi beds, and their limits can be distinguished by the lines of cliffs that they form overhanging the more gentle slopes of the softer schistose and slaty beds of the underlying Chaung Magyi Series. The boundary with the older rocks is deeply eroded, and exceedingly sinuous on account of the extremely deep, narrow ravines by which the whole of the State of Tawng-Peng is intersected. The outer boundary, as at Memauk, is characterised at the base by the development of conglomerates and grits, while they are absent from the inner boundary; and here

they rest with apparent conformity upon the graptolite beds beneath them.

**Lithology.**—The Lower Namhsim stage is essentially an arenaceous series ; the sandstones are either coarse in texture or fine-grained and compact, hard and splintery. Occasionally their boundary with the older rocks is marked by beds of coarse conglomerates, consisting of water-worn pebbles and boulders of the Chaung Magyi quartzites. In those places where the conglomerates do not occur, the sandstones are usually coarse-grained, and for some distance up from their base are strongly felspathic and usually of a bluish-grey or purple colour. These gradually become less felspathic, passing into fine-grained brown sandstones, with layers of hard, white, very fine-grained, quartzose sandstones. Their total thickness according to La Touche is at least 2,000 feet.

**Fossils.**—The following species represent the important fossils found in the Lower Namhsims :

**Brachiopoda** : *Mimulus aunglokensis*, *Orthis* sp.
**Mollusca** : *Orthonota* (?) *spectabilis*, *Pycnomphalus* sp., *Orthoceras* aff. *tenuiannulatum*.
**Arthropoda** : *Proetus* sp., *Encrinurus konghsaensis*, *Calymene blumenbachi*, *Cheirurus* cf. *bimucronatus*, *Phacops* (*Dalmanites*) *longicaudatus*, *Illaenus namhsimensis*.

**Tectonics.**—A close examination of the section exposed in the valley of the Nam-Tu, in the neighbourhood of Lilu, (see Fig. 13) reveals an overthrust which has brought the Naungkangyi beds to rest over the Lower Namhsim sandstones. Broadly speaking, the structure indicated is as follows : the Namhsim sandstones appear to overlap the Naungkangyi beds ; these were subsequently distorted by an overthrust fold or fault parallel to the Nam-Tu near Lilu, the beds having given way along the comparatively soft layers of the Naungkangyi shales, under the stress of an impulse acting from the east, and been driven up over the hard sandstone strata. The cause of such a dislocation having taken place along this particular line is perhaps to be found in the existence, only a short distance to the west, of the unyielding mass of the older Chaung Magyi rocks, forming the old land area of Tawng-Peng. The fault

plane runs almost due north and south, and has been traced from the Panghsa-pye saddle. Here it passes a short distance to the west of the village, into the Bawdwin area, to the north, where its effects are clearly observed in the twisted and shattered condition of the strata in its vicinity, and where the disturbance of the rocks brought about by it has, no doubt, facilitated the impregnation of the strata with the mineral ores for which the locality is so well known. A short distance to the south of Panghsa-pye village the fault dies out, as it has not been traced on the south side of the Nam-sam valley.

**Lower Namhsim Sandstones missing from Eastern Ranges.**—The Namhsim sandstones are entirely absent from the eastern ranges. La Touche thinks that they have either been overlapped by Plateau Limestone and denudation has not yet been able to expose them, or that this portion of the sea floor was so remote from the coast of that period that these sandstones were not deposited. He is more inclined to the latter view, as the Upper Namhsim marly beds are present in several places in this region.

## Upper Namhsim Stage or Kônghsá Marls.

The reason for dividing the Namhsim formation into an upper and lower division has already been indicated. The Upper Namhsim stage, which is marly in character, comes above the sandstones of the Lower Namhsim stage, wherever the latter are exposed ; but there are many places where these marls overlie directly the Ordovician Naungkangyi rocks. In such places the marls appear to represent the sandstones of the lower division. This fact is also confirmed by the great number of organisms common to both stages. It would, therefore, appear that the marls also were being deposited contemporaneously farther away from the shore while the sandstones were being laid down near it.

**Distribution.**—The Upper Namhsim beds or the Kônghsá marls are distributed in patches in several places on the Shan plateau. They are not known to exist close to the western edge of the plateau, however, but make their first appearance along the crests of the Pyintha ridge. They next crop out at

the northern edge of the plateau, a little to the south of Pangyu, where they form several low hills just beyond the boundary of

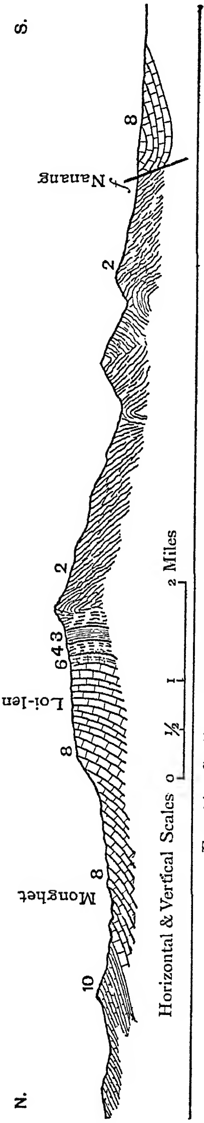


FIG. 14.—Section across centre of Loi-len range, Northern Shan States.

10. Namyan Beds.
9. Naping Beds.
8. Plateau Limestone.
7. Zebyingyi Beds.
6. Namhsim Sandstone.
5. Panghsa-Pye Graptolite Band.
*f*. Faults.
4. Hwe-Mawng Beds.
3. Naungkangyi Beds.
2. Chaung Magyi Series.

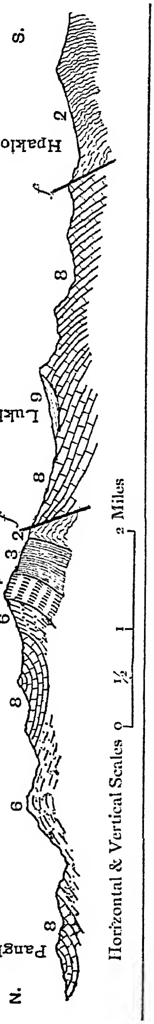


FIG. 15.—Section across the eastern end of Loi-len range, Northern Shan States.

10. Namyan Beds.
9. Naping Beds.
8. Plateau Limestone.
7. Zebyingyi Beds.
6. Namhsim Sandstone.
5. Panghsa-Pye Graptolite Band.
*f*. Faults.
4. Hwe-Mawng Beds.
3. Naungkangyi Beds.
2. Chaung Magyi Series.

the Plateau Limestone. In the Gokteik gorge the Upper Namhsim beds are very poorly represented, only one small outcrop having been discovered on the cart road between the eighty-eighth and eighty-ninth mileposts near the village of Pomaw. An outcrop, profusely rich in fossils, occurs close to the village of Kônghsá, from which the marls take their name, in a railway cutting about a mile west of Kyaukmé station. The rock here is a soft yellow marl, and the fossils are in the usual friable condition, but in much greater numbers and variety, including a species of *Fenestella*. On the east of the plateau they are exposed in the valley of the Nam-Tu and in the eastern ranges, not at the surface, but generally in sections.

**Fossils.**—Although the marls are comparatively of very small thickness they have yielded a large number of fossils. They include :

**Actinozoa** : *Lindstroemia* sp.

**Bryozoa** : *Fenestella* sp.

**Brachiopoda** : *Lingula lewisi*, *Leptaena rhomboidalis*, *Strophomena corrugatella*, *Orthotetes pecten*, *Orthis rustica*, *Orthis* (*Bilobites*) *biloba*, *Orthis* (*Dalmanella*) *elegantula*, *Orthis* (*Platystrophia*) *biforata*, *Pentamerus* cf. *oblongus*, *Conchidium* cf. *biloculare*, *Atrypa reticularis*.

**Mollusca** : *Pterinea konghsaensis*, *Conularia* sp.

**Arthropoda** : *Encrinurus konghsaensis*, *Calymene blumenbachi*, *Cheirurus* cf. *bimucronatus*.

**Annelida** : *Trachyderma* cf. *squamosa*.

**Relationships of the Fauna.**—As in the case of the Ordovician there is a strong contrast between the fauna of the Burmese and Himalayan Silurian, as is shown by the presence of graptolites at the base, which are absent from the Himalayan Silurian. This is in itself sufficient to show that there could have been no direct communication between the two areas during the Silurian period. The Himalayan Silurian is marked by the occurrence of corals, while only one species of coral has been obtained from the Burmese strata. In the latter there is also a great preponderance of trilobites, in variety and number, as contrasted with the Himalayan Silurian. These differences point out distinctly that the barrier which existed in the

Ordovician became more pronounced during the Silurian period. Furthermore, the Burmese fauna is more closely allied to its European representatives than to the American Silurian forms. In other words, out of the 40 species described from Burma no fewer than 35 (85·7 per cent.) are identical with, or allied to, European forms, and only 14 (35 per cent.) to American.

**Homotaxis.**—In the present state of our knowledge it is not possible to distinguish different zones in the Namhsims, and so their homotaxial relations have to be considered as a whole. In the Lower Namhsim stage there occur some species which are common to the Wenlock and Ludlow formations of England, or their nearest equivalents. The fossils of the upper stage also show great affinity to Wenlock and Ludlow fossils. But it may be noted that *Pentamerus* cf. *oblongus* and a *Lindstroemia*, closely allied to, if not identical with *L.* (*Petraia*) *subduplicata*, both characteristic of the Llandoverian of England, are found in Burma in the Upper Namhsims. The great majority of the fossils of the Namhsim stage are, however, characteristic of the Wenlock Series, so that the Namhsim stage, taken as a whole, may be considered to be homotaxial with the Middle Silurian, but having an admixture of higher and lower horizons.

### III. Zebingyi Stage.

Along the Mandalay-Maymyo railway line there occur close to Zebingyi station a group of limestones and shales which are remarkable for the occurrence in them of graptolites. On account of their distinctive characters they were separated from the underlying Namhsim stage and termed by La Touche the Zebingyi stage.

**Distribution.**—Besides the type locality near Zebingyi, graptolite beds are exposed in several places, as, for example, near the crest of the ridge east of the Zebingyi plateau, forming a narrow band running roughly parallel to the cart road from Pyintha northwards. They occur again along the same cart road near the twenty-ninth and thirty-second miles. Near Thondaung railway station a poor outcrop of this stage is noted, which is covered by Plateau Limestone and faulted against the Nyaungbaw beds. They are seen again at irregular intervals

between Zebingyi and Maymyo, especially close to Twinngé and again about half a mile north of Ani Sakán. Beyond Maymyo they are mostly concealed by the overlying Plateau Limestone either by faulting or by overlap, but are brought up here and there where sections occur.

**Lithology.**—This stage is largely a calcareous one with an admixture of shales. In the Zebingyi scarp it consists of grey, thin-bedded limestones, with numerous specimens of *Orthoceras* and an occasional trilobite, intercalated with shaly, carbonaceous layers containing *Tentaculites*. These are followed by limestones in thin regular bands separated by thicker layers of light-coloured shale and by dense black, if somewhat earthy, limestones, with thin partings of black shale containing graptolites and enormous numbers of *Tentaculites elegans*. The black limestones are succeeded by a series of flaggy, white, thin-bedded limestones, which pass upward conformably into the ordinary crushed type of the Plateau Limestone. The beds on the Lashio-Mongpyen road, which have yielded a small fauna without graptolites or *Tentaculites*, are probably on a higher horizon.

**Fossils:**

**Hydrozoa**: *Monograptus dubius*, *Monograptus riccartonensis*, *Monograptus* sp.

**Brachiopoda**: *Lingula* sp., *Stropheodonta comitans* var., *Atrypa marginalis*, *Atrypa* (*Atrypina ?*) *subglobularis*, *Meristina* sp.

**Pelecypoda**: *Modiolopsis shanensis*, *Lunulicardium* aff. *amabile*, *Dualina* sp., *Vlasta* sp., *Cypricardinia semisquamosa*.

**Pteropoda**: *Tentaculites elegans*, *Tentaculites ornatus*.

**Cephalopoda**: *Orthoceras* aff. *commutatum* and other species.

**Arthropoda**: *Phacops* (*Dalmanites*) *swinhoei*, *Entomis pelagica*, *E.* cf. *phalanga*, *Phacops shanensis*.

**Age and Homotaxial Relations.**—The fauna of the Zebingyi beds is quite distinct from that of the Namhsims. The presence of large numbers of graptolites indicates a Silurian age, and the great majority of the species are of Wenlock or Ludlow types. But there is also the fact that there is a great abundance of *Tentaculites elegans*, a characteristic Bohemian Lower Devonian

form which is here associated with graptolites. This might lead to the impression that in this part of the world graptolites may have survived even up to Devonian times. Stratigraphical evidence, too, is in favour of this conclusion. The Zebingyi formation, however, seems very closely analogous to the " passage beds " of the classic area in England on the borders of Shropshire and Herefordshire.

The faunas of the underlying Namhsim and Naungkangyi formations possess distinct affinities with those of northern and western Europe; but the fauna of the Zebingyi beds shows a greater resemblance to that of Bohemia and the Harz Mountains. This is especially the case with the beds on the Lashio road, described by Dr. Cowper Reed, which have a more decided Devonian facies. According to La Touche some considerable change in the distribution of land and sea must have taken place in the interval between the deposition of the Namhsim Series and the Zebingyi beds. According to the same authority " there had been throughout the Naungkangyi and Namhsim period some connection between the sea of Burma and those of Southern Europe, but not so direct as that with the seas of Northern and Western Europe; so that the fauna of the latter province frustrated any attempt of the southern fauna to travel eastwards: but that with the changes in the distribution of sea and land that began to take place at the close of the Silurian times, a more direct connection with Southern Europe was opened up." It is noteworthy that this fauna is not represented in the Himalayas.

**Tectonics.**—The Zebingyi beds have been bent into a syncline with the axis inclined towards the north, thus giving rise to a pitching syncline.

## SILURIAN OF SOUTHERN SHAN STATES.

Silurian rocks occur in the Southern Shan States, the survey of which is still in progress. From a well-marked horizon that overlies the Pindaya beds on the west large numbers of graptolites have been collected. Some of them have been examined by Miss Elles and provisionally determined as *Monograptus cyphus, Orthograptus vesiculosus* and *Climacograptus medius.*

These specimens are undoubtedly of Lower Valentian (Llandoverian) age.

Lower Palaeozoic fossils of Silurian age have also been found in the He-ho range and its northerly and southerly extensions have been proved to be considerably older than the Plateau Limestone of the Thamkhan range, as these Lower Silurian graptolitic horizons and an Upper Silurian *Tentaculites* horizon have been found near the junction of the two formations, where the two ranges join south of He-ho.[1]

At Pangkawkwo, near Loilem, Dr. Coggin Brown [2] found another richly fossiliferous graptolite horizon containing *Monograptus sedgwicki, M. regularis, M. distans, M. lobiferus.* According to Dr. Cowper Reed the same graptolite horizons of Silurian age exist in these localities as at Pinghsai and Ngai-tao in the Northern Shan States. At other localities Silurian rocks occur, for example near Loilem, where purple shales are found containing the coral *Palaeocyclus* sp. Fossils from these localities are now under examination.

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[1] *Rec. Geol. Surv. Ind.*, vol. lxvii, 1933, p. 47.

[2] *Rec. Geol. Surv. Ind.*, vol. lxvi, 1932, pp. 26-27.

# CHAPTER XV

## PLATEAU LIMESTONE

### I. DEVONIAN SYSTEM

La Touche gave the descriptive and comprehensive name of Plateau Limestone to a limestone forming the plateau country of the Federated Shan States with considerable extensions to the north and the south. In fact, this is the most widely prevalent formation in the Federated Shan States, and determines the general features of the plateau, which are due in a large measure to the peculiar constitution and mode of weathering of this rock. Wherever it is present it imparts a uniform character to the monotonous scenery, with wide shallow valleys, separated by low, swelling hills or ridges, succeeding each other, their outlines smoothed off by the universal covering of clay, except in the few places, where a scarp, usually indicating the line of a fault, presents a succession of precipitous cliffs to the view, or where a stream has cut a canyon-like gorge (see Plate X, Fig. 1) across it. Subsequently, however, La Touche divided the formation into two systems :

2. Upper Plateau Limestone (Anthracolithic), consisting of pure limestones, dark grey or bluish in colour, with *Fusulina* and *Productus*, occurring only in detached masses and almost inseparable from the lower beds.

1. Lower Plateau Limestone (Devonian), comprising crystalline dolomites and dolomitic limestones, which are considerably crushed, with traces of fossils, minute foraminifera and corals. An extremely rich Devonian fauna has been described from the Padaukpin coral reef and the Wetwin shales.

**Extent and Thickness.**—This limestone is found throughout the Northern Shan States. It extends into the Southern Shan States and the Karenni hills, and is probably continuous with some of the limestones in which the well-known caves in the neighbourhood of Moulmein exist. Towards the north similar

limestones have been observed in Yunnan. On the east they cross the Salween, while on the west they come, opposite Mandalay, right up to the edge of the alluvium.

Judging from these outlying masses it seems likely that this limestone once occupied a much greater area, which has since been considerably reduced by denudation. La Touche points out that no conglomerates have been found at its base wherever this is exposed. This would perhaps seem to indicate that the actual coastline of that period is not represented by the present boundary, but lay farther out on all sides.

The true thickness of the limestone cannot be determined as its upper limits are not properly known. Considerable allowance has therefore to be made for the great denudation it has undergone. La Touche deduced from his observations of the section in the deep gorge of the Nam-Tu near Lema and at the southern end of the great scarp south of Kyaukkyan, that the initial thickness must have been at least 3,000 feet.

**Lithology.**—The limestone is almost entirely dolomitic, and is in some places brecciated, in others sandy and argillaceous. Not infrequently it is extremely veined and crushed. In the words of La Touche the prevailing type of the Plateau Limestone is whitish or light grey, weathering to a darker grey, and often stained red by iron oxide both on the surface and along the joint planes. It is often hard enough to strike fire with a hammer, and when struck usually gives out a more or less pronounced fœtid odour, no doubt due to the presence of decomposed organic matter. In texture it is sandy to the touch and has a finely granular appearance, which at first gives one the impression that it is a siliceous limestone; but examination of thin sections under the microscope and chemical analyses show that the rock, except near its boundary with the older formations, where it occasionally passes into a sandy limestone, contains a very small proportion indeed of siliceous or argillaceous matter. One noteworthy feature of this limestone is that it occurs almost invariably in a crushed state, and is traversed by a number of interpenetrating calcite veins, often "faulted" and "slickensided," forming a kind of network. The extraordinary ease with which this limestone breaks up into small lumps in the quarries, where it is extracted, is noteworthy.

Thin sections of this limestone, examined under the microscope, have been found to consist of a granular aggregate of minute dolomite crystals with irregular outlines interlocking with each other. The individual crystals are usually clouded with brown semi-opaque matter, which is often concentrated in the centre, leaving a narrow clear zone round the edge. Where cavities are present the mineral filling them is clear, and frequently has a tendency, sometimes very pronounced, to crystallise in idiomorphic rhombohedra. Sometimes secondary calcite, however, is visible filling the fine cracks and veins. In the case of the brecciated dolomites the cementing material may consist either entirely of calcite or of a mixture of calcite and dolomite or dolomite alone. Sometimes the dolomites possess an oolitic texture and contain remains of foraminifera like *Endothyra*, *Textularia*, and *Trochammina* (?), of which the first is the most common. In some cases, the groundmass, the oolitic grains and the organisms are all, as shown by staining with Lemberg's solution, built of dolomite. It is noteworthy that these minute foraminifera are the only organisms to escape destruction, and this is in accordance with the observations of Dr. J. Murray and Mr. R. Irwin,[1] who concluded that when the shells of marine organisms are subjected to disintegrating influences those of the foraminifera are the last to disappear. Sometimes in the oolitic limestones the oolitic grains are sparsely scattered and are composed of calcite.

**Chemical Characters.**—Chemical analyses of this limestone have shown that its composition varies as follows :

| | | |
|---|---|---|
| Calcium Carbonate - - - | 55·55–62·06 | per cent. |
| Magnesium Carbonate - - - | 44·45–28·85 | ,, ,, |
| Ferric Oxide and Alumina - - | ·31– 2·11 | ,, ,, |
| Insoluble Residue - - - | ·07– 8·75 | ,, ,, |

The average chemical composition of six specimens as calculated by Coggin Brown [2] from the analyses quoted by La Touche is given below :

| | | |
|---|---|---|
| Calcium Carbonate - - - - - | 55·84 | per cent. |
| Magnesium Carbonate - - - - - | 43·05 | ,, ,, |
| Ferric Oxide and Alumina - - - | 0·54 | ,, ,, |
| Insoluble Residue - - - - - - | 0·7 | ,, ,, |

[1] *Proc. Roy. Soc. Edinburgh*, vol. xvii. p. 99.

[2] *Geol. Surv. Ind.*, vol. lxv, 1931, p. 410.

The average of five specimens collected by G. de P. Cotter from the Loi-an neighbourhood in the Southern Shan States is 43·49 per cent. of magnesium carbonate.

The specific gravities of these limestones have been found to range from 2·717 to 2·841. This is a fairly good indication of the amount of magnesium carbonate they contain ; the specific gravity of pure dolomite being about 2·90, while that of calcite is 2·70.

**Origin of the Dolomites.**—The very small amount of insoluble residue in these limestones points to their having been formed under coral reef conditions. Subsequently the limestones underwent dolomitisation, which also brought about the destruction of the organisms that originally built the rock. According to La Touche the almost complete dolomitisation of the whole mass of the Lower Plateau Limestone is an indication that deposition went on in a slowly subsiding area, whereby the mineralising agents present in sea-water had sufficient time to have complete effect. Some of the dolomite present in fissures and cavities, however, is of secondary origin, and was deposited direct from solution.

**Tectonics.**—As compared with the overlying formations of the Mesozoic epoch, which have been thrown into very acute folds, the Plateau Limestone seems to have been affected in a different manner, except perhaps in the eastern ranges, where it has been inclined at gentle angles not exceeding 30 degrees. Reference, however, has already been made to the highly crushed nature of these rocks. In addition, they are traversed by networks of calcite or dolomite veins, which are frequently faulted across by others, and slickensided surfaces are quite common, indicating that differential movements have taken place in the mass and that the movements were spread over a long time. The same cause may be adduced for the occurrence of the re-cemented breccia.

Another cause which might have accentuated the effects of dynamic stresses is chemical action. Limestone is a rock which is easily capable of going into solution in carbonated waters. The Plateau Limestone has been undergoing denudation for a long period, and percolating waters containing carbon dioxide have produced enormous cavities in it by removing the lime

in solution. When this process goes on for a long period a gradual settling of the formation takes place, which sets up great strains in the lower portions. So dynamic stresses, either alone or in conjunction with the pressure exerted by the settling down of the whole formation, may have caused the complete recrystallisation of the limestone and the almost entire destruction of all organic remains.

**Fossils.**—It is indeed remarkable that the closest search has failed to reveal to the naked eye any traces of organisms. Such fossils as have been found are confined to the superficial unaltered portions of the formation. The foraminifera have been detected only with the aid of the microscope. The only fossil that has been found in a fit state for identification is *Fusulina elongata* from Tonbo. Here the fossil was obtained from the compact and splintery upper portion of the Plateau Limestone.

According to La Touche, a clue to the possible composition of the formation and to the general unfossiliferous nature of the limestone may be gathered to some extent by a study of the Padaukpin coral reef. In the latter case mollusca are very rarely met with, and even then only their casts have been discovered. This is probably due to their shells having been composed of aragonite, which is less stable than calcite. It would seem therefore that the Plateau Limestone contained molluscan shells, originally, largely composed of aragonite. It seems that La Touche is postulating these limestones to have been originally organically formed, but it is quite possible that they were mainly chemically produced by the precipitation of the calcium carbonate from solution in the sea-water. Furthermore, it is not certain whether brachiopod faunas contain very large numbers of lamellibranchs, even when developed, as it seems that conditions are perhaps not suitable for both groups to thrive simultaneously.

### II. Padaukpin Coral Reef.

The monotony of the vast thickness of the unfossiliferous limestones is broken in one or two places, *e.g.* at Padaukpin, a village which lies exactly a mile east by south from Wetwin railway station. Here the outcrop is very small, and according

to La Touche is not more than 50 yards in length and 6 feet in thickness. The numerous fossils from this locality include corals, crinoids and brachiopods, etc. The more important ones are listed below :

Actinozoa : *Cyathophyllum ceratites, Cyathophyllum birmanicum, Cyathophyllum bathycalyx,* and other species, *Endophyllum acanthicum, Diphyphyllum symmetricum, Zaphrentis* aff. *cornicula, Amplexus hercynicus, Hallia quadripartita, Aulacophyllum looghiense, Cystiphyllum* (*C. cristatum* and *vesiculosum*), *Microplasma fractum, Calceola sandalina, Favosites goldfussi, Pachypora reticulata, Alveolites* (*A. suborbicularis, ramosa* and *subplanata*), *Trachypora davidsoni, Heliolites interstinctus.*

Hydrozoa : *Stromatoporella granulata, Actinostroma clathratum.*

Crinoidea : *Storthingocrinus fritillus, Cupressocrinus* cf. *crassus, Hexacrinus* aff. *pyriformis,* and *H. elongatus, Taxocrinus* sp.

Bryozoa : *Fistulipora quaerenda, Fistulipora tempestiva, Fistulipora cunctata, Fistulipora memor, Eridopora multidecorata, Selenopora coelebs, Buskopora semilunata, Fenestella arthritica, Fenestella* aff. *polyporata, Fenestrapora isolata, Hemitrypa oculata, Hemitrypa inversa, Polypora* (*P. populata, P. birmanica, P. ultimata*).

Brachiopoda : *Stropheodonta interstrialis* var. *birmanica, Stropheodonta subtetragona* var. *padaukpinensis, Strophonella caudata, Leptaena rhomboidalis, Orthothetes umbraculum, Chonetes* (*C. minuta* and *C. sarcinulata*), *Orthis* (*Schizophoria*) *striatula, Orthis* (*Rhipidomella*) *eifeliensis, Pentamerus* (*Gypidula*) *brevirostris, Pentamerus* (*Gypidula*) *biplicatus, Camarophoria lummatoniensis, Rhynchonella* (*Hypothyris*) *cuboides* and other species. *Atrypa reticularis, Spirifer padaukpinensis* and other species. *Cyrtina heteroclita, Athyris concentrica.*

Pelecypoda : *Avicula* sp., *Conocardium rhenanum, Paracyclas proavia* and *P. rugosa.*

Gastropoda : *Platyceras compressum* and *P. orientale, Loxonema* aff. *rugiferum* and other species, *Pleurotomaria*

sp., *Murchisonia* sp., *Euomphalus radiatus*, and *E. wahlenbergi*, *Bellerophon lineatus*, *Dentalium* sp., *Orthoceras* aff. *laterale*.

**Arthropoda :** *Phacops latifrons*, *Phacops* (*Dalmanites*) *punctatus*.

**Annelida :** *Spirorbis omphalodes*.

**Composition and Relationships of the Fauna.**—From the above it will be readily seen that the Paudaukpin fauna is characterised by an abundance of corals, bryozoa and brachipods, and by a scarcity of other groups. The corals are not only abundant in genera and species but also in individuals. Mollusca are very rare, and most of the genera are represented only by a few species; the reason for this paucity has already been given above. In the opinion of Dr. Cowper Reed the fauna is composed of an assemblage of cosmopolitan, European, American, and Oriental forms. But among them the European types are notably predominant, and many of the forms are identical with, or closely allied to, species from the Middle Devonian or *Calceola* stage of Western Europe, with a typical Rhenish facies. In a similar limestone near Padaukpin Dr. Cowper Reed has found large masses of the coral *Phillipsastrea* and the brachiopod genus *Douvillina* which suggest the presence of an Upper Devonian horizon, the *Calceola* fauna being here absent.

As stated by La Touche, it is possible that the Padaukpin fauna furnishes an instance of the concentration of more than one zone within a small thickness of strata, owing to deficiency in sedimentation, as in the case of the *Tropites* limestone described by Dr. Carl Diener in Byans,[1] where a bed of limestone includes both the Carnic and Noric stages of the Trias.

## III. Wetwin Shales.

The other fossiliferous locality in the Plateau Limestone is situated near the village of Wetwin, about 12 miles east of Maymyo. Here the fossils have been obtained from a shaly horizon, the outcrop of which was traced by La Touche for just

[1] *Pal. Ind.*, Ser. xv, vol. v, Memoir No. 1, 1906, p. 200.

over a mile to within half a mile of the *Calceola* beds of Padaukpin. The relations of one deposit to the other cannot be made out; however, they seem to underlie, if continued, the *Calceola* beds, but it is not at all certain if a fault does not separate the two. The character of the fauna of the shales, however, indicates a higher position. The shales, which are very argillaceous, and somewhat resemble a hard and fissile "Fuller's earth," with a generally yellowish buff colour mottled with pink or dark grey stains, have been termed the Wetwin Shales. In these shales there is a great preponderance of pelecypods, and the fauna here is very different from that of Padaukpin.

**Fossils.**—Of the many fossils found in this locality the following are the most important ones:

**Bryozoa:** *Fenestella polyporata*, *Polypora* sp.

**Brachiopoda:** *Lingula* cf. *ligea*, *Lingula* cf. *punctata*, *Chonetes subcancellata*, *Rhynchonella* (*Camarotœchia*) sp., *Athyris* cf. *spiriferoides*.

**Pelecypoda:** *Janeira birmanica*, *Nucula wetwinensis* and other species, *Palæoneilo* sp., *Paracyclas* sp.

**Gastropoda:** *Bellerophon shanensis*, *Bellerophon* (*Phragmostoma*) *admirandus*.

**Arthropoda:** *Echinocaris asiatica*.

**Pisces:** *Ichthyodorulite*.

The comparison of the Wetwin and Padaukpin faunas at once reveals their marked dissimilarity, both in their composition and affinities. The former bears a close relationship to some American faunas, especially those belonging to the Hamilton or Middle Devonian group of that country, as no fewer than 24 species out of 30 are comparable with the American forms, and the occurrence of the almost exclusively American genus *Palaeoneilo* is the most conspicuous instance of this affinity. The Wetwin Shales are marked by the prevalence of lamellibranchs, while these are scarce on the other horizon. It is held that this may be due to special conditions of deposition, and that the Wetwin Shales may have been deposited in a lagoon with only a slight connection with the open sea.

Shaly bands also occur in the Plateau Limestone in other places, but on account of their easy removal by denudation

they are not to be seen at the surface. But in fresh sections or cuttings they may be observed, as in the railway cutting a little to the west of Letkaung village at the foot of the final ascent to Maymyo, and also in the cutting about three miles to the east of Kyaukmé station. These are also fossiliferous, but only a few indeterminable specimens of *Lingula*, shells of a minute *Estheria*, somewhat resembling *E. mangilensis*, and a few fragmentary plant remains have been obtained.

## IV. Lower Plateau Limestone of Southern Shan States.

The Plateau Limestone in the present state of our knowledge is by far the most widespread rock formation of the Southern Shan States as well, though it is not yet possible to state its exact extent. As usual, the Lower Plateau Limestone is a dolomitic rock, which is highly crushed, and possesses almost the same characteristics as described above for the Northern Shan States.

J. Coggin Brown confirms that the Thamakan-Heho ridge is composed of Plateau Limestone, and according to him white dolomites crop out in the railway cuttings at the foot of the ascent near mile 389·5 and there are plenty of exposures about mile 387. Grey brecciated dolomites are seen in the valley of the stream flowing to the south-east, around which the line circuits near this point. The rounded slopes of hill 4,568 show a few low cliffs of grey and stained yellowish-brown rock, while dolomites are quarried for ballast near the summit.

J. Coggin Brown crossed the extension of the Heho range, between Poila and Kyauktap, and followed its western edge south down the Poila valley, finding Plateau Limestone all the way. Typical brecciated dolomites occur in the neighbourhood of Kyong. Its western boundary lies to the west of Poila and Pindaya, where it overlies the older Ordovician rocks. On the east it abuts against the older rocks of the Mawsön Highlands. It attains considerable dimensions in the neighbourhood of Taunggyi, the capital of the Federated Shan States. According to J. Coggin Brown [1] the limestones extend to mile 28–3, east of Taunggyi, where they terminate at the

[1] *Rec. Geol. Surv. Ind.*, vol. lxvi, 1932, p. 98.

crest of the ridge between the two Shan States of Hopong and Möng Pawn. Both divisions of this formation are represented, the lower consisting of grey brecciated dolomites, sometimes friable enough to be kicked to powder, with, oftener, harder greyish white, re-cemented material with a deceptive sandy appearance and occasionally banded with pink.

### V. Devonian Limestones in Yunnan and China.

Bituminous limestones and shales of Middle Devonian age have been found in Yunnan and Central China. It is concluded from their lithology that the Devonian sea towards the north in these regions was narrow and more shallow than in the south, occupying the site of the Shan States and Malay Peninsula, but later on in the Carboniferous period underwent further submergence, since we find great thickness of similar limestone in China as in the Shan Plateau.

### VI. Age.

It has not been found possible to determine precisely the age of the Lower Plateau Limestone, since by insensible gradation it passes on into the Upper Plateau Limestone, but it is known to bridge over a period from Upper Silurian to Carboniferous.

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# CHAPTER XVI

## PLATEAU LIMESTONE

### I. ANTHRACOLITHIC (PERMO-CARBONIFEROUS) SYSTEM

IT has already been noted that the dolomitic limestones of Devonian age pass by insensible gradations into grey or dark blue limestones, which in places, as at Tonbo, etc., have yielded remains of *Fusulina elongata* and other fossils. Though both the physical and chemical characteristics of the two limestones are distinct, yet it has not been found possible to map the two formations separately owing to the marked lateral and vertical variations they exhibit.

**Distribution.**—These younger limestones occur as outlying masses capping ridges and knolls with rugged precipitous walls of rock. In the Northern Shan States, fossils on this horizon were first discovered by P. N. Datta in 1901, who recorded the occurrence of *Fusulina* in a limestone found at the crest of a ridge a few miles west of Tong-Ang ferry on the Nam-Tu, and also farther to the east of Ho-un. In the Southern Shan States Middlemiss was the first geologist to report the existence of limestone containing *Fusulina elongata* and other fossils from outcrops along the Government cart road leading eastwards from Taunggyi. The other localities in the Northern Shan States, where similar fossils have been found, are Namún near Mankang on the northern slopes of the Loi-len range, and Kehsi-Mansam, the capital of the State of that name. Besides the above, limestone containing *Fusulina elongata*, associated with corals and sometimes with brachiopods, but in too bad a state for identification, has been found at several other places in the Northern Shan States, showing that this formation had once a much greater extension over the plateau.

**Lithology.**—The rock containing *Fusulina elongata* and other fossils, is an exceedingly minutely crystalline limestone, generally dark blue, grey or black in colour, with a much more strongly fœtid odour than the limestones below. They do not exhibit the sandy texture of the underlying limestones, but are much more compact and possess a conchoidal fracture. The variety seen at Kehsi-Mansam is thinly bedded, dark grey or black in colour.

**Chemical composition.**—Chemically they are true limestones, and, as a rule, contain under one per cent. of magnesium carbonate. The average chemical composition of four analyses of the Permo-Carboniferous limestones, quoted by La Touche, is given below :

| | |
|---|---|
| Calcium Carbonate - - | - 98·39 per cent. |
| Magnesium Carbonate - | - 1·37 ,, ,, |
| Ferric Oxide and Alumina | - 0·49 ,, ,, |
| Insoluble residue - - | - 0·48 ,, ,, |

However, the variations in percentages of these constituents are as follows :

| | |
|---|---|
| Calcium Carbonate - - | - 96·0–99·39 per cent. |
| Magnesium Carbonate - | - 0·16– 4·23 ,, ,, |
| Ferric Oxide and Alumina - | - 0·35– 0·79 ,, ,, |
| Insoluble residue - - | - 0·27– 0·91 ,, ,, |

The specific gravities of these samples varied from 2·68 to 2·70. A specimen of a variety of this limestone from Poila in the Southern Shan States yielded 0·91 per cent. of magnesium carbonate.

**Conditions of Deposition.**—It has been mentioned in the preceding chapter that the great thickness of Devonian Plateau Limestones was deposited in a slowly sinking sea, when the magnesium carbonate had enough time to react and replace the calcium carbonate of the original limestone formed of coral reefs. But the limestone of Permo-Carboniferous age consists of almost pure calcium carbonate. According to La Touche this difference in chemical composition is due to a complete change in the mode of deposition, *i.e.* the sea after the deposition of these younger limestones underwent a rapid upheaval, which did not permit the alteration of the original composition of the

limestone. He also suggests, however, that perhaps this difference may have been due to the Devonian dolomites being composed of the shells of mollusca largely composed of comparatively less stable aragonite, while the Permo-Carboniferous limestones were composed of brachiopods and corals.

**Fossils.**—The following are the important species found in this formation. The importance of the brachiopods in the fauna will be noticed, and especially the occurrence of so peculiar a type as *Oldhamina*, which is confined to the Indian region:

**Foraminifera**: *Fusulina elongata.*

**Anthozoa**: *Lonsdaleia indica*, *Amplexus* sp., *Zaphrentis* sp., *Syringopora* sp., *Cyathaxonia* sp.

**Crinoidea**: Indeterminate crinoid stems.

**Bryozoa**: *Hexagonella ramosa*, *Fenestella* cf. *perelegans* with some other species, *Polypora* cf. *ornata* and other species.

**Brachiopoda**: *Spirifer fasciger*, *Spirifer striatus*, *Spirifer condor*, *Martinia dispar*, *M. orbicularis*, *Reticularia* cf. *lineata*, *Martiniopsis latouchei*, *Spiriferina cristata*, *Spirigera royssii*, *Spirigerella derbyi*, *Streptorhynchus shanensis*, *Schizophoria indica*, *Rhynchonella imitatrix*, and *R. michelinii*, *Oldhamina* sp., *Productus cora*, *P. tenuistriatus*, *P. cylindricus*, *P. gratiosus* and other species, *Strophalosia costata*, *Chonetes grandicosta*, *Dielasma biplex* and *D. plica*, *Notothyris simplex*, *Camarophoria* sp., *Marginifera* sp.

**Pelecypoda**: *Pseudomonotis* sp., *Aviculopecten* sp., *Schizodus* sp., *Pecten* sp.

**Arthropoda**: *Phillipsia* sp.

**Cephalopoda**: *Xenaspis carbonaria*, *Nannites* sp., *Ammonites* sp.

**Gastropods**: *Trochus* sp., *Pleurotomaria* sp., several species of *Naticopsis*, *Holopella* sp., *Murchisonia* sp., *Neritopsis* sp., *Platyceras* sp.

The cephalopods and gastropods mentioned in the above list were recently collected by M. R. Sahni[1] from a series of thinly

[1] *Rec. Geol. Surv. Ind.*, vol. lxvi, 1932, pp. 97-98.

bedded argillaceous limestones and shales amongst the dolomites of the Plateau Limestone at Na Hkyam in the Northern Shan States. The association of ammonites and gastropods and the complete absence of brachiopods in this fauna is unique. The evidence with regard to the age of the beds from which the cephalopods and gastropods were collected is somewhat conflicting. *Xenaspis carbonaria* is a Productus Limestone form. *Holopella trimorpha* comes from the same beds. They therefore indicate a Permian horizon. On the other hand the genus *Xenodiscus*? has not been recorded from rocks older than the *Otoceras* beds of Lower Triassic age.

**Relationships of the Fauna.**—The relationship of the fauna of the Northern Shan States with the American forms, noticed in the previous system, was still continued, as shown by the occurrence of *Fusulina elongata* and several bryozoa and brachiopods. One noteworthy feature, however, that is at once perceptible, is its striking resemblance to the Permo-Carboniferous fauna of the Salt Range and Central Himalayas, indicating the connection of the Shan and the Salt Range seas. How this connection took place is not at all clear. In the opinion of La Touche " the very close similarity between the Middle Productus fauna of the Salt Range and that of the Shan States seems to require a more direct connection between the respective seas than would be afforded by a communication by way of the northern branch of the Tethys alone." The connection with the China seas seems to have remained also, though the number of species common to both regions is small. The fauna, enumerated above, has also a very close resemblance to the Permian and Carboniferous faunas of Russia, 29 out of 78 Shan species being identical. This is only to be expected, owing to the resemblance that exists between the fauna of the Salt Range and that of the Urals. A connection with the Malay Archipelago also is suggested by the occurrence there of a few species found in Burma on the same horizon.

**Age.**—These limestones, in the opinion of Diener and La Touche, are on the same horizon as the Middle and Upper Productus Limestones of the Salt Range and the " exotic block " of Chitichun No. I in the Central Himalayas, which are of Permo-Carboniferous age.

## II. Anthracolithic Limestones of the Southern Shan States.

The occurrence of the younger Plateau Limestones, capping the dolomitic limestones of Devonian age in the Southern Shan States, has been referred to above. Their physical and chemical characteristics are exactly the same as those mentioned for the Northern Shan States and need not be repeated here.

According to F. W. Walker the Thamakan-He-ho ridge is composed of Plateau Limestone, which J. Coggin Brown has identified as perhaps belonging to the upper divisions of Permo-Carboniferous age. The rock varies from a light grey to a pale blue colour and it is greatly crushed and brecciated, though a few outcrops with good stratification are also seen. The occurrence of *Fusulina* sp. just to the west of Pindaya, and of clisiophyllid corals and *Lyttonia* sp. near Naungkaya, prove that the limestones in this neighbourhood belong to the Permo-Carboniferous section of the Plateau Limestone.

It has already been stated above that, according to Dr. Coggin Brown, the Plateau Limestone extends up to mile 28-3, east of Taunggyi. Both divisions are represented, and the upper one comprises thin-bedded, concretionary, tabular bryozoan limestone with interbedded marly and shaly layers. The latter rocks are very fossiliferous and contain abundant bryozoa, brachiopods and corals. The brachiopods include *Productus* sp. and *Lyttonia* sp.

The other known occurrence of fossiliferous rocks of this age is between miles 36–5 and 37–2 on the Taunggyi–Loi-len road, where similar limestones and calcareous shales occur. They form a low cliff on the west bank of the Pawn river overlooking the Möng Pawn plain and possess a low easterly dip.

The faunas from these localities have recently been described by Dr. Cowper Reed ; the rarity of the genus *Productus* is a noticeable feature, but the abundance of bryozoa is conspicuous.

**Limestone of the Myitkyina District.**—In the north, limestone apparently belonging to the Plateau Limestone group has been found in the Kamaing subdivision of the Myitkyina district, where small outcrops of this rock are common. The colour of the rock varies from cream to black, but various shades of grey and blue are also present. In places, the rock is coarsely crystalline,

in others it is brecciated. In one place the limestone near the contact of the peridotites and serpentines has been metasomatically replaced by silica and it appears to be a black chert. Perfect rhombohedral crystals of dolomite are developed in the rock, undoubtedly as a result of the serpentine intrusion.

Fossil organisms, *Fusulina* sp., *Fenestella* sp., *Textularia*, and various forms of *Globigerinidae*, which the author [1] found in the bedded limestone, tend to prove its Permo-Carboniferous age.

## III. Moulmein Limestone Series.

In the Tenasserim division there exists a group of limestones with sandstones and clays which are found to rest upon the gneisses of the Archaean system and also on the argillites of the Mergui Series. To this group of rocks the term " Moulmein Group " was first applied by T. Oldham.

Lithologically this group is composed of red, white or yellow sandstones with thin earthy partings, grey shaly beds, which are occasionally calcareous, thinly-bedded and fine sandstones, and massive black limestones. Of all these, the limestone bed at the top alone covers a wide area of the country. The aggregate thickness of this group, excluding the limestone bed at the top, is nearly 6,000 feet, while the thickness of the limestone bed alone is about 1,100 feet. It is probable that the underlying reddish sandstones and marls belong to the older Palaeozoic systems, and the limestones, therefore, have been separated from them and designated the Moulmein Limestone Series.

The Moulmein limestones comprise coarse, crystalline and unfossiliferous limestones. According to Sethu Rama Rao they are coarse-grained in the Mergui district, where some of the crystals measure from $\frac{1}{4}$ to $\frac{1}{2}$ inch in width.

The rocks form prominent ridges and hills with precipitous sides, sometimes standing like fortresses and surrounded by alluvium. As mentioned already they contain caves of various dimensions.

According to Sethu Rama Rao one of the chief outcrops of the limestone of the Moulmein Series is the Thampra Hill and

[1] *Rec. Geol. Surv. Ind.*, vol. lxii, 1929, p. 108.

a range of precipitous hills to the south. This outcrop constitutes with others a limestone chain from the source of the Ngawun *chaung*, the southern tributary of the little Tenasserim river. The chain crosses the Great Tenasserim and continues westwards to the well-known limestone hills of Kyauktaung and Tharabwin. This central chain is the longest and best exposed. Another eastern line parallel to this was observed by Vinayak Rao near the mouths of the Beluhsekhan and Khuhtaokhan rivers at their confluence with the Tenasserim.

The westerly line of the limestones is seen in isolated islands in the Mergui Archipelago. The "High Black Rocks" and "High Rocks" islands lying to the west of Tavoy Island and to the east of Middle Moscos, which are visible from Maungmagan, are the northernmost outcrops of this line. The central group of this line is represented by the Turret Islands, while the southernmost group constitutes St. Matthew's Island. Farther north precipitous hills of Moulmein Limestone are seen rising from the plains in the Amherst district.

**Chemical Composition.**—A specimen of limestone collected by Sethu Rama Rao from the Turret islands yielded the following results on chemical analysis :

| | |
|---|---|
| Calcium Oxide - - - | 55·51 per cent. |
| Magnesium Oxide - - - | 1·00 ,, ,, |
| Oxide of Iron and Alumina - | 0·27 ,, ,, |
| Loss on Ignition ($CO_2$ and $H_2O$) | 43·72 ,, ,, |
| Insoluble residue - - - | 0·10 ,, ,, |
| | 100·60 |

Its specific gravity was 2·764.

Another specimen collected by P. N. Bose and analysed in the laboratory of the Geological Survey of India had the following chemical composition :

| | |
|---|---|
| Calcium Carbonate - - - - - | 85·85 per cent. |
| Magnesium Carbonate (by difference) - | 0·14 ,, ,, |
| Oxide of Iron and Alumina - - - | 0·61 ,, ,, |
| Insoluble in dil. HCl - - - - - | 13.40 ,, ,, |

From the above it will be seen that these limestones, like the Upper Plateau Limestone of the Shan Plateau, are true limestones, and do not contain much more than one per cent.

of magnesium carbonate. In physical and lithological characters also they bear a close resemblance to the Anthracolithic limestones described above from the Federated Shan States.

**Fossils.**—The Moulmein Limestones have yielded fossils in very few localities, and it is difficult to extract them on account of the rock being tough and compact like the Upper Plateau Limestone of the Shan States. A list of those collected by P. N. Bose near Kyauktaung, north-west of Tharabwin, and identified by Noetling, is given below :

> *Schwagerina oldhami*, *Lonsdaleia salinaria*, *Lithostrotion* sp., *Polypora* cf. *biarmica*, *Productus* cf. *sumatrensis*, *Athyris* sp., *Spirifer* sp., *Bellerophon* sp., *Pleurotomaria* aff. *durga*. *Murchisonia* sp.

**Age.**—The above fossils indicate an Upper Carboniferous age for these limestones. Captain F. W. Walker collected *Productus* from the limestones of the Amherst district. The late J. W. Gregory also collected from rocks near Martaban a fossil which has been identified as *Palaeanodonta okensis*. This locality is not on the Moulmein Limestones, but on rocks probably belonging to the same series. The original horizon of this fossil is the Middle Permian of the Oka-Volga basin, near Nizhni-Novgorod.

## IV. Comparison of the Northern and the Southern Shan States.

It has recently been brought to light by J. Coggin Brown and V. P. Sondhi that the Lower Palaeozoic succession in the Southern Shan States is more complete and widespread than its homotaxial equivalents described by La Touche from the Northern Shan States. The lithological characters of the rocks making up the succession are also more varied. The Upper Plateau Limestone is better displayed and yields more varied faunas in this area than in the north. On the other hand, some of the important rock groups of the Northern Shan States, such as the Chaung Magyi Series, the Namhsim Sandstones and the fossilferous Namyau Series, have not been found yet in the south.

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# CHAPTER XVII

## THE MERGUI SERIES

It was T. Oldham who first gave the name Mergui Series to an unfossiliferous formation consisting of the great group of grits, crushed shales, agglomerates, conglomerates, limestones and quartzites, which occur so widely in the Tenasserim division and occur stratigraphically below his Moulmein Series, which includes limestones that are known to be Carboniferous in age. As these rocks are highly indurated and totally devoid of fossils, and as thick vegetation covers a great portion of the outcrops, the exact determination of their age has not been possible. That they are metamorphosed sedimentary rocks overlying the gneissic rocks of the division is now beyond doubt. For their distribution in the Tavoy and Mergui district reference may be made to the map, Plate XXVI.

**Lithology.**—The various rock types that have been recorded as constituting the Mergui Series are argillites, greywackes, agglomerates, quartzites, conglomerates and limestones.

**Argillites.**—According to Drs. Coggin Brown and Heron the predominant member of the Mergui Series in the Tavoy district is the argillite, a fine-grained rock of a blue-grey to black colour when fresh, with obscure bedding and only incipient cleavage. Near contacts with granite small crystals of pyrites are common. Jointing is very close, splintery and irregular, and where the rocks are slightly affected by weathering without being decomposed into lithomarge they break up easily into small angular fragments. The association of the carbonaceous argillite carrying small crystals of andalusite and sillimanite with finely divided graphite is noted in the sequel. It is remarkable that the carbonaceous argillite does not develop, on weathering, the typical reddish-brown colour of the

normal argillites, but remains black and yields a blackish soil. Similar carbonaceous shales having a graphitic appearance have been found in several places in the Mergui district, and the best exposures are to be seen near Tharabwin, Mawton and Tagu.

**Greywackes and agglomerates.**—The rock type that is next in importance to the argillites in the Tavoy district is the dark-grey or almost black "greywacke" or agglomerate which weathers to an ashy or brown colour. This rock is composed of a confused and structureless aggregate of sub-angular fragments of fine-grained rocks in a matrix identical with the material of the argillites. The fragments consist of quartz, slate, fine quartzite, felspar, and are usually smaller than a grain of wheat, with an occasional one as large as a hazel nut. Some rounded pieces of granite, about three inches in diameter, have also been observed both in the Tavoy and the Mergui districts. This proves the existence of a pre-Mergui granite, which so far has not been located. According to Dr. Coggin Brown and Dr. Heron these rocks very strongly resemble volcanic tuffs, and as coarse agglomerates of undoubted volcanic origin, described below, have been found in the Mergui Archipelago, they must represent the finer ejectamenta of paroxysmal eruptions. They are extremely hard and tough, and show no stratification or cleavage. They are traversed by a system of cross-joints. Included in them are broad bands of the argillites described above, with an incipient cleavage parallel to the general strike.

The occurrence of volcanic rocks in Maingay, Elphinstone and other outer islands of the Mergui Archipelago is described in Chapter XXVIII. Sethu Rama Rao observed similar rocks, resembling ash beds, weathering to a grey colour, on Singu Island, north of Kyaukpeik, which island forms the southerly continuation of the Elphinstone Island rocks. Another easterly band of hard, tough, indurated volcanic tuff containing angular fragments of felspar and sub-angular pebbles of slate of various sizes, occurs on the easterly slopes of Manoron *taung* at the source of the Pon *chaung*, one of the tributaries of the Manoron *chaung*, N.N.W. of Thetke.

Impure sandstone-quartzites are met with occasionally as an

arenaceous modification of the argillites, and occur interbedded with them. A broad zone of purer quartzites crosses the Tavoy river above and below Shintabi. It consists of a mosaic of quartz clouded with aluminous material, and is traversed by veins of finer quartz. Although they do not give rise to great heights they form bold and rugged ridges, and the beautiful gorge of the Tavoy river between Kyaukshat and Sanchi is cut through them. True conglomerates are very rare, and are only very occasionally met with in the Tavoy district, but in the Mergui district they are more common, and are found interbedded with the argillites. The pebbles consist of granite, quartz and quartzite, ranging in diameter from one to ten inches. From the nature and size of the boulders it appears that they have not travelled far. Some of the pebbles are of mudstone and jasper and have flat surfaces.

Thin-bedded and generally impure limestones of blackish or red colour have been observed at various localities in river beds. There are two varieties: one is a fine-grained, homogeneous, though much shattered type; the other white and saccharoidal, full of irregular knots and streaks of ferruginous and clayey material. These occur as masses or thin shaly bands dipping south-west or west-south-west at 40 degrees. In the south, in the Mergui district, the series is composed of quartzites, slates, phyllites, quartz grits, conglomerates, argillites, and kaolinised sandstones. It is to be noted that the quartzites and sandstones are the predominant rocks of the Mergui district, hence the rock facies is rather of an arenaceous character in the south as contrasted with their argillaceous character in the Tavoy district. Indurated sandstones occur on Singu Island, and can be traced from the village of Singu southwards, through Yechudaung Island to Shwegenyo and Awebindat. On weathering the rock crumbles to white sand. These rocks are traversed by quartz veins and pegmatities which sometimes carry cassiterite, but not in sufficient quantities to be of economic value, except in rare cases. They have been extensively invaded by granite.

**Amherst District.**—The Mergui Series is known to extend to the north in the Amherst district, and consists of an assemblage of highly folded and indurated sedimentaries, and, as in the

south, is extensively intruded by bosses of granite. The predominating member is a hard blue slate, roughly cleaved and often arenaceous. Quartzites, which in places are somewhat argillaceous, are associated with it. Sandstone-conglomerate was observed at two places in the Ye-Lamaing township.

**The granite-sedimentaries contact.**—Where metamorphism has been intense the argillite described above is altered into phyllites, or even mica-schists with pyroxenes and garnets. In the Mergui district, according to Sethu Rama Rao, there are many instances where the argillite is altered into hornstone along the periphery of the granite. On the island of Pulo Kamat the argillite metamorphosed by the granite has the appearance, but not specific gravity, of basalt. Under the microscope a thin section reveals the presence of brown biotite, magnetite and garnet. Further, the most frequent effect of contact metamorphism is the production of a compact, tough quartzite of a paler colour than the argillite, probably from the fusion and recrystallisation of the silica in it with also perhaps the addition of some silica from the magma during its consolidation. Carbonaceous argillite carrying small crystals of andalusite and sillimanite with finely divided graphite has also been recorded. In the north in the Amherst district the rocks of the Mergui Series are metamorphosed into micaceous quartzites, quartz-schists, gneissic and felspathic quartzites and schists and paragneiss. Again, from the presence of quartz and felspar in many of the metamorphosed sediments, it would appear that the granite masses have contributed a considerable amount of silica to the argillaceous rocks where these come into contact with them.

**Tectonics.**—The general strike of the beds of the Mergui Series is N.N.W.–S.S.E., and this direction coincides with the trend of the mountain ranges and also the longer axes of the granite intrusions. However, the strike may vary locally from north-south to north-west—south-east.

The dip of the beds, wherever observed, is always high, approaching verticality in places. It is believed by Drs. Coggin Brown and Heron in the Tavoy district and Sethu Rama Rao in the Mergui district that the vast extent over which these rocks are exposed is due to their folding. Owing to very thick

vegetation and heavy soil cap few good sections elucidating the structure are observed. However, long traverses in an east-west direction reveal the reversal of dip, proving folding. According to P. N. Bose the beds are contorted, and he says: "In the Upper Tenasserim valley, on the west side of the river the dips chiefly point westward, and on the east side they are mostly found directed eastward, so that the main Tenasserim valley would appear to lie along a denuded anticline." The King Island is again thrown into an anticlinal fold, whose axis coincides with that of the main ridge of the island. At times anticlinal and synclinal folds are repeated, and in places the strata are closely compressed in folds within a width of 50 yards. Sethu Rama Rao states that in the eastern portion of the Mergui district the dips are steep, in the western portion and in the islands they become more and more gentle. J. J. A. Page has observed the crossing of two anticlines in Hayes Island (12° 30′, 89° 10′), and also steeply dipping folds on an island off the south-west corner of Elphinstone Island.

All these folds are roughly parallel to one another. As the overlying Moulmein Limestone is also folded, some of the crustal movements must have occurred in part subsequent to their deposition, *i.e.* post-Permo-Carboniferous; but since there is a considerable difference seen in the degree of folding and metamorphism of the Mergui and Moulmein Limestone Series, earlier folding, *i.e.* pre-Moulmein Series, must have also played its part. However, this difference in folding may well be due to the difference in competency between the argillaceous Mergui Series and the Moulmein Limestones. Limestone, as a rule, shows bolder folds than argillaceous rocks, which are inclined to "crinkle."

The Mergui Series as seen in some of the Mines is cut up by small strike faults, but their throw seldom exceeds a hundred feet. According to Drs. Coggin Brown and Heron a large fault runs through the Heinze Basin, but no direct evidence is available to prove its existence. The suggestion is tentatively advanced, as shown above, because of the marked subsidence which the basin has undergone.

**Age.**—The age of the Mergui Series is one of the most controversial problems in Burmese geology, and the views of the

Malayan and Burmese geologists are not quite in accord. No fossils have yet been found in it in Burma. The Moulmein Limestone, which apparently overlies the Mergui Series, has been proved by its fossils, collected by P. N. Bose, to be Carboniferous, so the Mergui Series must be at least pre-Carboniferous. But from lithological resemblance, and the degree of metamorphism it has undergone, it was in the past tentatively correlated with the Chaung Magyi Series of the Federated Shan States—pre-Cambrian and, possibly in part, older Palaeozoic. In the valley of Ngawun, a tributary of the little Tenasserim, the Mergui Series was found conformably underlying the Moulmein Limestones. This, according to J. B. Scrivenor, may be equivalent to the argillaceous Carboniferous rocks of the Langkawi Islands. Vinayak Rao [1] reports that the Merguis appear to have passed gradually into the Moulmeins. According to Sir Edwin Pascoe, if this be so, and the older rocks truly identified as the Mergui Series, the idea regarding the age of the latter which has up to the present been thought to be the equivalent of the Chaung Magyi Series, may require modification.

Dr. W. R. Jones assigns a Carboniferous age to the limestone and a Permo-Carboniferous age to a part of the Mergui Series. According to Sethu Rama Rao,[2] however, the limestones referred to by Dr. Jones as forming the bed of the Kanbauk valley are not the typical limestones of the Moulmein Series, and he has given many instances where similar limestones are interbedded with the Mergui Series in the Tavoy and Mergui districts.

In the Amherst district in the north P. Leicester has given the name of Taungnyo Series to the sandstone-shale series seen so well-developed in the Taungnyo range. The Taungnyo Series is overlain by the Moulmein Limestone, and he considers that there was no great lapse of time between the deposition of the shales comprising the upper beds of the Taungnyo Series and the limestones. Should this prove to be true it would be necessary to assume either that the Taungnyo Series is younger than the Mergui Series, or that in reality the latter is of more recent age than at present assumed, its

[1] *Rec. Geol. Surv. Ind.*, vol. lv, 1923, p. 80.

[2] *Mem. Geol. Surv. Ind.*, vol. lv, 1930, pp. 14-15.

greater degree of metamorphism being due to the extensive granite intrusions in the country to the south. As even the views of the Burmese geologists are at variance it therefore appears that until more data are forthcoming the age of the Mergui Series must remain an open question.[1]


REFERENCES

1. Brown, J. Coggin, and Heron, A. M., "Geology of the Tavoy District," *Mem. Geol. Surv. Ind.*, vol. xliv, 1923, pp. 178-184.
2. Pascoe, Sir Edwin, "General Report for 1929," *Rec. Geol. Surv. Ind.*, vol. lxiii, 1930, pp. 93-97.
3. Rao, Sethu Rama, "Geology of the Mergui District," *Mem. Geol. Surv. Ind.*, vol. lv, 1930, pp. 10-15.


[1] In a private communication to me, Mr. J. B. Scrivenor after reading the typescript of this chapter, stated that he has a "strong suspicion that what has been mapped as one Mergui Series in Burma is equivalent to the Malayan Trias and the Malayan Lower Carboniferous." The presence of carbonaceous argillites—the Mergui Series—yielding a blackish soil suggests that these rocks are the equivalent of the Malayan Trias; but on the other hand, the thin-bedded impure limestones and the garnets in the metamorphosed rocks indicate that these rocks at least are the equivalents of those which underlie the Carboniferous limestone in the Langkawi Islands. On the mainland, these have yielded Carboniferous fossils.

## CHAPTER XVIII

### TRIASSIC SYSTEM

As explained later, there is a big hiatus between the Permo-Carboniferous limestones of the Northern Shan States and the succeeding Napeng beds of the Rhaetic stage. Similarly, beds of Triassic age occur in the Southern Shan States. Farther south limestones with Upper Triassic fossils have been recorded from the Amherst district. On the west rocks of Mesozoic age occur in the Arakan Yoma where rocks of Triassic age constitute the oldest formation of which the age is definitely known.

In the following table the general classification of the Mesozoic rocks, as developed in Burma, is shown. For the Shan plateau Dr. Fox's[1] arrangement is retained, but it is not certain whether the Cretaceous age of the Namyau shales, as given by him, is final.

### Napeng Beds (Rhaetic Stage).

The whole of the Shan plateau at the end of the deposition of the Plateau Limestones was upheaved from the bottom of the sea and the dawn of a new era in the geological history of that region was marked by a tremendous break in the sequence of sedimentation. From stratigraphical evidence it has been concluded that there was no deposition at all in the Shan plateau over a great part of the Permian and almost the whole of the Triassic periods. During this interval of time the Plateau Limestone was under the influence of the subaerial denuding agents. It was only during very late Triassic times that sedimentation commenced again in this region, and these newer

[1] *Rec. Geol. Surv. Ind.*, vol. lxiii, 1930, p. 185.

| Age. | | Northern Shan States. | Southern Shan States. | Karenni Hills. | Amherst District. | Mergui District. | Arakan Yoma Series. |
|---|---|---|---|---|---|---|---|
| Cretaceous | Upper - - | Namyau Shales | "Red Beds" of Kalaw. | | | | Negrais Series with *Cardita beaumonti* beds, Mai-i series. |
| | Middle | | | | | | |
| | Lower | | | | | | |
| Jurassic | Upper Oolite | | | | | | |
| | Lower Oolite - | Namyau Limestones | | | Red Sandstone series. | Red Sandstone series. | |
| | Lias - - | | Loi-an Coal measures. | | | | |
| Trias | Rhaetic - - | Napeng Beds. | — | *Halobia* Limestone. | Kamawkala Limestone (Upper Triassic). | — | Axial Series with *Halobia* Limestone. |
| | Keuper | | | | | | |
| | Bunter | | | | | | |
| Permian | Upper - - | Upper Plateau Limestone. | Upper Plateau Limestone. | Upper Plateau Limestone. | Moulmein Limestone. | Moulmein Limestone. | |
| | Middle | | | | | | |
| | Lower | | | | | | |

deposits overlie the older formations with a marked unconformity. The deposits of Rhaetic age, which are extensively developed to the east and south-east of Napeng village, nine miles east of Pyaung-gyaung railway station, have been termed the Napeng beds by La Touche.

**Distribution.**—The Napeng beds are very capriciously distributed in patches at widely separated points over the Northern Shan States. West of the Gokteik gorge they have been only found at Kyaukkyan, at a point where the railway crosses the great fault scarp between Hsum-Hsai and the gorge. They also occur at Kyinsi and Mansam. In all these places the relationships with the overlying and underlying strata are not clear, as good sections are not exposed. In the Napeng area this relationship is all the more masked by the irregular contortion of the strata. According to La Touche, any considerable break between the Napeng and the overlying Namyau Series is very unlikely.

**Lithology.**—The lithology of the Napeng beds is very different from that of the preceding formations. In keeping with their uneven distribution their lithology also varies from place to place. Broadly speaking, these beds are composed of highly argillaceous, yellow-coloured shales or indurated clay, very much resembling the Wetwin shales. In some places they are calcareous and pass into clunchy, sandy marls, or tough, argillaceous, thin-bedded limestones. Beds of a hard, dark-blue limestone, containing fragments of shells, spines of echinoids and foraminifera, and indistinguishable at first from the Plateau Limestone, are sometimes also interbedded with the shales. In the Napeng area the rocks of this horizon are soft, yellow shales or sandy marls, sometimes passing into hardened, grey, calcareous shales with an occasional band of blue limestone. One type of this limestone which occurs as a persistent band at, or quite close to the base, is a dense, compact, splintery rock consisting of fragments of shells with minute foraminifera like *Textularia*, *Miliola*, which are visible only in thin sections under the microscope.

**Conditions of Deposition.**—According to La Touche the Napeng beds were deposited in the cup-shaped hollows or depressions formed in the Plateau Limestone, when it was

undergoing denudation during later Permian and Triassic times. The sea was just deep enough to fill up the depressions, while some of the higher portions of the limestone still stood above water. This would explain the uneven and capricious distribution of the formation, and such an explanation is supported by the nature of the fauna found at the various localities.

**Local Disturbance of the strata.**—The Napeng strata show the very variable amount of disturbance they have undergone. In places they are almost horizontal or tilted only very slightly, while within a space of a few yards they may be highly contorted and disturbed. La Touche was of the opinion that this was due to underground solution of the Plateau Limestone, which brought about the slipping and settling down of the overlying strata, resulting in the disturbance of the overlying Napeng beds. Similar phenomena were observed by Medlicott in Assam, where the Tertiary sandstones and shales overlie the Nummulitic limestones.

**Fossils.**—It is noteworthy that the fossils of these beds contain survivals of one or two Palaeozoic forms which caused in the beginning considerable controversy with regard to their age. The examination of the fauna by Miss Healey settled the Rhaetic age of these beds. The following are the important species found :

**Anthozoa:** *Lophosmilia praecursor, Isastraea confracta.*
**Brachiopoda:** *Lingula nanimensis.*
**Pelecypoda:** *Palaeoneilo fibularis, P. nanimensis, P. currirostris,* and *P. whitchurchii, Nucula peelii, Grammatodon lycetti, Pinna* cf. *blanfordi, Concocardium superstes, Gervillia shanorium, G. praecursor, G. rugosa* and *G. napengensis, Perna obruta, Alectryonia* sp., *Pteria (Avicula) contorta, Myophoria napengensis* and *M. tenuis, Plicatula carinata,* and *P. difficilis, Burmesia la touchei* and *B. lirara, Prolaria sollasi, Pecten quotidianus, Modiola frugi, Datta oscillaris, Cardita singularis, Protocardia contusa, Cardium nequam, Modiolopsis* sp.
**Gastropoda:** *Promathilda exilis, Turritella* sp., *Loxonema* sp.

**Composition and Relationships of the Fauna.**—The composition of the fauna offers a strange contrast to those of

the formations preceding it, with the exception of the Wetwin shales. It is composed almost entirely of lamellibranchs with a few gastropods and a single brachiopod. However, very little is known of the fauna of the limestones associated with the Napeng shales. In the former only sections of brachiopods, gastropods and spines of echinoderms have been recognised. The similarity of the Napeng fauna to that of the Wetwin shales is very noteworthy, and it is believed that the two formations were deposited under similar conditions. The recurrence in the Napeng beds of the American genus *Palaeoneilo*, the most common fossil at Wetwin, strengthens this conclusion.

Two new families, *Burmesiidae* and the *Dattidae*, were established in the fauna of the Napeng beds, and out of the eighty-one species described by Miss Healey forty-three were new to science. Only three species are identical with European forms. This appears to be an indication of the vast changes that must have taken place in the distribution of land and sea during the period that intervened between the Permo-Carboniferous period and the deposition of the Napeng beds. It also appears that the basin in which these beds were deposited was isolated. The occurrence of a few species found in the Napeng beds, in China, Sumatra and the Malay Archipelago is an indication of the extension of this basin in these regions. It therefore appears that the equivalents of the Napeng beds had a fairly wide distribution in the Eastern seas of the Rhaetic period, but that in each case the fauna possessed a distinctly local character. The absence of any common forms in the Himalayan and Salt Range regions is indicative of the isolation of the Napeng basin from the Tethys.

**Age.**—For a long time the age of the Napeng beds remained unsettled, and it was not till the year 1903, when the specimens were examined by Professor Suess and afterwards by Miss Healey, that their Rhaetic age was fixed with certainty. *Pteria* (*Avicula*) *contorta*, *Myophoria* and *Grammatodon lycetti* are characteristic Rhaetic fossils.

## Trias of the Karenni Hills.

Very little is known of the Trias of the Karenni hills, except that a hard black limestone containing *Halobia* and *Monotis* occurs there.

## Kamawkala Limestones, Amherst District.

It seems likely that the limestones of Permo-Carboniferous age described above extend upward into the Trias in the eastern part of the Amherst district, where Dr. Cotter collected fossils of Triassic age and gave these limestones the name of Kamawkala Limestones, from a village beside the Thaungyin river, which there forms the boundary between Burma and Siam. They crop out near the Htichara Forest bungalow, about three miles north of Htichara, and extend northwards from this point, so as to join up in all probability with the limestones exposed in the Kamawkala gorge of the Thaungyin river, which lies about fifteen miles to the north. According to Dr. Cotter similar limestones are found south and west of Phalu and in the hills south of Thingannyinaung and extend farther east into Siam. Professor Gregory was of the opinion, however, that the Htichara limestone is different in character from that found along the Thaungyin.[1]

The limestone is of a grey colour, hard and crystalline, frequently showing a network of veins of calcite. According to Professor Gregory it is comparatively little altered and is not dolomitised. The Htichara limestone, on the contrary, has been greatly altered, the carbonate of lime has become crystalline calcite, while the bulk of the rock consists of small crowded crystals of dolomite. The same authority was of the opinion that "the Htichara Limestone appears to be so different in character as to be probably older."

**Fossils.**—Fossils of Triassic age, probably Noric, have been found in these limestones. They include corals, a few brachiopods, lamellibranchs, fragments of ammonites, sponges, spines of echinoids and calcareous algae.

[1] *Rec. Geol. Surv. Ind.*, vol. lxiii, 1930, p. 157.

**Corals:** *Stylophyllopsis thaungyinensis, Centrastrea cotteri, Meandraraea orientale.*

**Brachiopoda:** *Rhynchonella bambagensis*, with several other indeterminate species of the same genus.

**Pelecypoda:** *Chlamys* aff. *valoniensis.*

**Ammonites:** *Trachyceras* sp.

**Algae:** *Diplopora* sp., *Holosporella siamensis.*

These fossils indicate an Upper Triassic horizon though Dr. Trauth was of opinion that their age is most probably Carnic to Noric.

**Transgression of the Sea in Burma in Upper Triassic time.**—According to Professor J. W. Gregory the discovery of this Triassic marine limestone on the Burmo-Siamese frontier is interesting, as it links the Triassic limestones of Spiti and the Himalaya with those in the East Indies, where they have yielded a rich fauna in Timor. The East Indian and the Alpine Triassic faunas are so similar as to suggest the continuation of the sea between them. The Himalayan Trias of Spiti and that of Timor in the East Indies include representatives of all stages from the Lower to the Upper Trias. On the other hand, Lower and Middle Trias are missing from the Thaungyin area, and it was believed by Gregory that the sea reached this locality by a transgression in the Upper Trias, as was also the case in Northern Yunnan, where the Upper Trias contains corals and brachiopods and the Lower Trias is continental as in many parts of the Pacific coast.

## Trias of the Arakan Yoma.

The main mass of the Arakan Yoma is built of Triassic, Cretaceous and Eocene rocks, consisting mostly of altered sandstones, shales and limestones. They were in all probability deposited in a shallow arm of the "Tethys." As noted previously, there appears to have been no direct communication between this sea and the Shan-China seas except by way of the "Tethys." The country which lies between the Brahmaputra and the Salween, *i.e.* the northernmost parts of Burma, appears, according to La Touche, to have been a stable land dividing

the Arakan sea from the Shan-China seas. This portion, though not well explored geologically, is yet known to be composed of very ancient crystalline rocks which possibly constituted a barrier between the Arakan and the Shan seas.

**Classification.**—The pre-Tertiary rocks of the Arakan Yoma have been divided as follows, in descending order :

| | |
|---|---|
| Negrais Series - - - - | Cretaceous and (?) early Eocene. |
| Mai-i Series - - - - - | Cretaceous. |
| Axial Group and Chin Shales - | Triassic-Cretaceous. |

## Axial Series.

Theobald gave the name of "Axial" to a group of altered rocks building the main Arakan Yoma. Subsequently, however, he divided the group into two, the name Axial was restricted to the older division, considered to be of Triassic age, while the name Negrais was applied to the younger rocks, possibly of Cretaceous or even later age.

**Extent and Tectonics.**—The Axial beds are confined to the Prome and Thayetmyo districts, while the Chin Shales are developed in the Minbu and Pakokku districts. In the north the Axial beds constitute the central core or the axis of the Arakan range and form a wedge-shaped outcrop which merges indistinctly into the altered Negrais rocks in the south : on the eastern side they are well demarcated by a pronounced fault at their junction with the Eocene rocks. This fault, according to Theobald, dies out to the south, together with the Axials themselves, under the highly disturbed Negrais Series. The Axials at the junction are highly inclined and are packed together, much squeezed and contorted. They terminate in the south in the Thanni stream, and their western boundary, in the opinion of Theobald, probably coincides with the valley of the Gamon stream, a tributary of the Mai-i river. Whilst the Axial beds occupy the axis of the range in the north they do not coincide with it to the south, but run down obliquely from it until they terminate against the Nummulitic boundary, which lies well into the outer hills. The maximum breadth of the outcrop, as recorded by Theobald,

does not exceed twenty miles. The rocks seem to be very tightly folded and compressed.

**Lithology.**—Theobald has divided the Axial strata into Lower and Upper divisions, and the following is the section as observed by him in the Hlowa stream :

| | |
|---|---|
| Lower Axials | |
| Shales and sandstones (seen) - - - | 300 ft. 0 in. |
| Upper Axials | |
| (*a*) Halobia limestones, shales, etc. | 33 ft. 3 in. |
| (*b*) Freckled grits, etc. - - | 1,364 ft. 6 in. |
| (*c*) Shales and sandstones - | 2,197 ft. 0 in. |
| (*d*) Sandstones, etc. - - - | 147 ft. 0 in. |
| | 3,851 ft. 9 ins. |

Theobald had placed the Cardita shales at the base of the Upper Axials, but they have yielded fairly well preserved specimens of *Cardita beaumonti*, a species which is characteristic of the Upper Cretaceous of Sind and Baluchistan. It is, therefore, certain that the Axial group of Theobald is a mixed one comprising both Triassic and Cretaceous beds.

The Lower Axials are composed of shales and sandstones ; the shales are mostly thin-bedded and flaggy ; they exhibit a dark or greenish colour and sometimes contain carbonaceous markings.

The Upper Axial strata have been studied in detail on account of the good exposures met with in accessible places. These consist of shales and sandstones with limestone bands and serpentine intrusions. The shales are mostly ill-bedded : they have been much crushed by dynamic stresses and by serpentine intrusions. They are either black, greenish or grey in colour. Near the contact with serpentine they have been highly contorted and extremely altered to either mica- or graphite-schists. The contact is also often marked by large quantities of silica occurring as quartz veins. These shales usually weather to a clayey soil.

Associated with the shales and sandstones are bands of crystalline limestones of various tints ranging from pure creamy white to pink and yellow. Wherever the streams cut through Axial strata blocks of this crystalline limestone may be seen.

Theobald called this rock, which has yielded evidence, though only meagre, regarding the age of the beds, the *Halobia* Limestone.

The next division (*b*) in the above list is the most important, as from the peculiar petrological character of the beds it enables them to be recognised with certainty, wherever met with. It consists of white speckled grits and conglomerates, not usually very coarse, and cream-coloured argillaceous sandstones, often having a sub-porcellanous appearance. Small white quartz pebbles abound in the finer conglomerates, but the coarser conglomerates are mainly composed of argillaceous sub-schistose rocks. In the lower part of the Hlowa stream an enormous thickness of these beds, which are greatly disturbed and faulted towards the boundary, is exposed. Higher up the stream the dip is more regular and always high but varies in direction. Some of the sandstones are hard and massive and have strings of quartz pebbles irregularly disseminated through them.

**Fossils.**—The only Triassic fossils that have been discovered so far, are *Halobia lomelli*, specimens of *Monotis* and *Avicula* from the limestones, and a few indeterminate gastropods from the shales. *Halobia lomelli* is a characteristic Triassic fossil in the Himalayas of Spiti.

## Chin Shales.

It is not unlikely that part of the Chin Shales of Noetling represents the Axial group of Theobald farther north. Lithologically the Chin Shales consist of flysch-like shales and hard limestones. Noetling [1] added that "Mr. Theobald's so-called 'Axial group' of the southern part of the Arakan Yoma, which he considered of Triassic age, represents in a broad sense these shales." But it requires considerable work in the Arakan Yoma before any proper correlation can be attempted. Though Noetling included the Chin Shales in the Tertiaries, it seems certain that they, at least in part, represent the older rocks. According to Cotter [2] "the Lakis are underlain by the

[1] *Rec. Geol. Surv. Ind.* vol. xxviii, 1895, p. 62.
[2] *Op. cit.* vol. xli, 1912, p. 322.

Cretaceous or 'Chin Shale Series' on the eastern flanks of this part of the Arakan Yoma." The Chin Shales, therefore, like the Axials, again represent a composite group including both the Trias and the Cretaceous.

### Axials of Manipur and Naga Hills.

Similarly, rocks belonging to the Axial group and possibly of Triassic age were observed by R. D. Oldham in the Manipur and Naga hills. They consist of a series of slates, sandstones and quartzites. In the north of Manipur and in the Naga hills, on the road from Manipur to Kohima, which runs along the strike of the rocks, only grey and black slates are seen with a north-south strike, and a high, generally vertical dip. In the Angami Naga country quartzites are found not infrequently interbedded with jet-black and grey slates, and the strike of these rocks shows occasional variation. Oldham referred them to the Axial group of the Tangkul country.

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# CHAPTER XIX

## JURASSIC SYSTEM

THOUGH the occurrence of Jurassic rocks has been known in the Northern Shan States for some time it was only recently proved that a belt of these rocks, mostly consisting of red sandstones, extends, as described below, from the Shan Plateau through the districts of Amherst and Mergui to Tonkin in Southern Siam. Though no definite fossils have been discovered from the Amherst and Mergui districts, yet from their similarity to the known Jurassic occurrences of the Northern and Southern Shan States and farther south in Siam there is little doubt that they are the intervening links in the chain of Jurassic rocks found in Burma and Siam.

### Namyau Series, Northern Shan States.

The Napeng beds are succeeded by red or purple sandstones and shales with bands of limestone to which La Touche gave the name of Namyau Series, as they were found very well developed in the Namyau valley. It is believed by La Touche that there is no unconformity separating the Napeng beds from the series under description, and the absence of the former at the base of the overlying formation may be accounted for by irregularities in the floor of the Plateau Limestone, upon which they were deposited. The sea, it appears, during the deposition of the Namyau Series had spread itself horizontally, though without increasing its depth to any extent, as the Namyau beds constitute a shallow water facies, bearing ripple-marks.

**Lithology.**—In some places the basal members of the Namyau beds are conglomerates, consisting of well-rolled pebbles of Plateau Limestone and other older rocks, set in a sandy, calcareous matrix. These may perhaps be local equivalents of the Napeng beds. Good examples of this conglomerate are seen in the Nam-

Tu valley, a short distance above the Ta-Ti ferry, on the trade route leading north from Hsipaw, and at Htengnoi lower down the river. After the deposition of the conglomerates the sea gradually deepened when alternating layers of sandstones, shales and clays with bands of limestone were deposited. The distinguishing feature of the rocks of this series is their colour, which is generally a dark red, often with a decided purplish tinge; but beds of grey, pepper-and-salt coloured sandstones, and bands of yellow clay are sometimes interstratified, especially in the higher parts of the series. The sandstones are mostly soft and friable and are therefore easily susceptible to the influence of weathering agents. They are only very occasionally hard enough to be used for building purposes. The limestone bands of the Namyau Series are usually homogeneous in texture, and are very compact and fine-grained; but are often argillaceous and abound in fossils, passing into shelly limestones.

Being easily weathered the limestones form no conspicuous feature, but they denote very clearly the direction of the strike of the formation, viz. N.N.E. to S.S.W., and also the profound disturbance that the rocks have been subjected to, for they generally dip at high angles, not infrequently approaching verticality.

**Distribution.**—La Touche believes that the Namyau beds must have had a much wider distribution once, and they have been entirely worn away from the western portion of the plateau. No beds of Jurassic age have been met with to the west of the Gokteik gorge. On the east they occur at the confluence of the Nam-hsim with the Nam-Tu near Bawgyo; to the north and south of Hsipaw they occupy wide areas and are especially developed in the valley of the Namyau river. They occur again to the east of Lashio beyond the Namma coalfield on the Namyau. They extend into Yunnan and also into Szechuan and other parts of China. One notable feature is, that the boundaries of the Namyau beds generally coincide with faults and the red beds have been let down among the hard limestones by faulting, which fact is responsible for their preservation from complete denudation.

**Fossils.**—The fossils of the Namyau beds are entirely brachiopods and lamellibranchs. The remarkable point to be noticed

is the total absence of ammonites or cephalopods which at this period were common in the Central Himalayas and Kachh. The fossils include the genera *Burmirhynchia*, *Holcothyris*, *Orthotoma*, *Terebratula*, *Pecten*, *Alectryonia*, *Modiola*; but species belonging to the first two genera are the most common.

**Age.**—Buckman considered it advisable to divide the Namyau Series into a Lower Namyau limestone and an Upper Namyau shales. In his opinion "It may be that two quite distinct formations differing considerably in age" occur in the Namyau Series. On general considerations it has been held that the Namyau Series are probably equivalent to the Bathonian (Bradford Clay, Cornbrash and Kellaways Rock) of England.

## Loi-an Series, Southern Shan States.

Coal-measures of Jurassic age were described by Dr. Cotter as the Loi-an Series from the Loi-an coalfield, three miles east of Kalaw in the Southern Shan States. According to him "the coal-measures of Loi-an are separated from the red sandstone of Kalaw by a ridge of intervening limestone and the relationship between the two is rather obscure, though it is possible that both groups are part of one series, the Red Sandstone series." However, as described below, Dr. Fox[1] has recently obtained cephalopods of Cretaceous age from the "Red Beds" of Kalaw. Dr. Cotter divided the coal-measures of Loi-an into a lower shaly zone, a middle zone, in which sandstones predominate, and an upper zone containing coal seams. The Legaung ridge is built up of coarse quartzitic sandstones with intercalations of mudstone and shale containing irregular seams of coal. They show high convergent dips. A narrow band of Plateau Limestone runs along the top of the ridge. From one locality specimens of *Alectryonia* sp. and crinoid stems were collected.

**Fossils.**—The roofs of the coal-seams are generally fossilferous, and Dr. Cotter and Captain Walker found the following plant remains in them:

**Filicales** : *Cladophlebis denticulata.*
**Gingkoales** : *Gingkoites digitata.*

[1] *Rec. Geol. Surv. Ind.* vol. lxiii, 1930, pp. 182-187.

**Coniferales** : *Pagiophyllum divaricatum*, *Brachyphyllum expansum*.
**Bennettitales** : *Ptilophyllum* sp.
**Incertae sedis** : *Podozamites distans*.

**Age.**—According to Dr. Cotter: "*Gingkoites digitata* is a cosmopolitan Jurassic species, *Pagiophyllum divaricatum* occurs in the lowermost Cretaceous (Umia) group of Kachh, *Brachyphyllum expansum* occurs in the Vemavaram beds (age, Upper Lias to Lower Oolite) . . . while *Podozamites distans* is found in the Lias at Rajmahal. The age of the coal is therefore Jurassic, but it is not yet possible to state whether it is Lias or Oolite . . . the fossil flora definitely proves the coal-measures to be later than the Plateau Limestone and close in age to the Namyau series of La Touche, which contains a brachiopod fauna of Bathonian (lower Oolite) age."

### The Red Sandstone Series, Amherst District.

The Red Sandstone Series of Jurassic age is well developed in the eastern part of the Amherst district near the borders of Burma and Siam. The hills of red sandstone possessing rounded contours can be distinguished easily at a distance from those of the limestones possessing typically pinnacled or craggy scenery described above. The series under description overlies the Kamawkala limestone unconformably and consists predominantly of a pink or brick-red to purple sandstone of fine to medium texture. It is not infrequently pebbly. The pebbles are usually small, not exceeding an inch in diameter, and are composed of either pink sandstones or white quartzite. The pebbles are sparsely distributed in the sandstone and are often angular to sub-angular. Associated with the red sandstones are clays of colours varying from grey to cherry-red, conglomerate bands and buff-coloured sandstones. Intercalated with the clays are thin layers of argillaceous limestones, about one to three inches thick. The latter have yielded traces of fossils, mainly lamellibranchs, amongst which the genus *Astarte* is common. The red sandstones and clays are steeply dipping or vertical, but have a moderate dip in the neighbourhood of Myawaddi.

With the red sandstone is associated a calcareous conglomerate composed of pebbles or boulders of Moulmein or Kamawkala limestone, and red sandstone set in a matrix of red sandstone. In the Thaungyin river there are eight exposures of this conglomerate over a distance of six miles. According to Dr. Cotter the source of derivation of the red sandstone boulders is not known. If they were derived from the Red Sandstone group, then they are younger than it, but there is no evidence to support such a conclusion. Dr. Cotter grouped these conglomerates provisionally with the Red Sandstone Series, but with the *proviso* that they may possibly be of later age or at least a high horizon in the Red Sandstones. The strike of the conglomerates is parallel to the hill-ranges of the neighbourhood.

### The Red Sandstones of Mergui District.

In the Mergui district Sethu Rama Rao classified the rocks of the Red Sandstone Series as follows, in descending order :

D. Purple sandstones, shales and conglomerates.
C. Fine-grained pinkish sandstones and shales with patches of white clay.
B. Calcareous sandstones.
A. Conglomerates and grits.

**Distribution.**—The Pataw and Patit islands lying off the coast near the town of Mergui are composed of the basal conglomerates and grits, which unconformably overlie the Mergui Series. The remaining three, B, C and D, in the above list build the chain of islands commencing from Gladys Island and Kyunzauk in the north to Panadaung *taung* and Thityawa islands in the south. The intervening islands of Dorcas, Kataungbyo, Kyunbon and Satkyun are made of these rocks.

**Lateral variation.**—These sediments show a lateral variation. The northernmost islands, Gladys, Kyunzauk, etc., are composed of fine-grained sandstones of a reddish tint, while the rocks of the Thityawa islands are coarse and approach grits and conglomerates in texture. The noteworthy feature of these rocks is that they contain fresh felspar, pebbles of quartz and slates,

showing thereby that the valley or estuary, in which they were laid down, must have been surrounded by hills of granite and slate. In fact, a line of granite hills runs almost parallel to the chain of islands constituting the Red Sandstone Series.

The strike of the rocks of the Red Sandstone Series is 20° east of north to 20° west of south and they dip in the direction 20° south of east.

**Fossils.**—So far the series has yielded no fossils, though Dr. Dudley Stamp collected specimens of silicified fossil wood and impressions of partly carbonised wood from it.

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# CHAPTER XX

## CRETACEOUS SYSTEM

recently it was believed that rocks of Cretaceous age were absent from the Shan Plateau. In 1929, however, Dr. Fox found two cephalopods of undoubted Cretaceous age in the "Red Beds" of Kalaw. In the table of classification,[1] he has placed the Namyau Shales of the Northern Shan States in the Cretaceous system.

### Southern Shan States.

In the Southern Shan States "Red Beds," composed of very soft, friable sandstones and shales of purplish-red colour, occur at and in the neighbourhood of Kalaw, and overlie the Loi-an Series of Jurassic age. From the little hillock, crowned with a small *pagoda* and lying between the railway-station and the Kalaw hotel, Dr. Fox collected specimens of *Turrilites* sp. and *Baculites* sp. The identifications were made by Dr. Cotter, who was of the opinion that these cephalopods were similar to those from the Trichonopoly beds of the Madras Coromandel Coast, which are Upper (Ariyalur) to Middle (Utatur) Cretaceous in age.

These "Red Beds"[2] are also found flanking the Legaung ridge on both sides, and north of Singu occupy almost the whole of the Panlaung valley, where, west of the river, porphyry and dolerite are seen intruding into them.

### The Arakan Yoma.

Marine fossils including *Exogyra*, *Nerinea*, *Orbitoides*, etc., in addition to *Cardita beaumonti*, have been collected from the

[1] *Rec. Geol. Surv. Ind.* vol. lxiii, 1930, p. 185.

[2] *Rec. Geol. Surv. Ind.* vol. lxvi, 1932, p. 102.

foothills of the Arakan Yoma in the Thayetmyo district, while *Mortoniceras inflatum* and *Placenticeras* sp. have been recorded from the Yoma in Arakan. T. H. D. La Touche[1] during his travels from the Myittha valley across the Chin hills collected some echinoids, which proved to be of Cretaceous age.

### Mai-i Series.

In the Arakan Yoma undoubted Cretaceous rocks occur only on the west in the Sandoway district, where a single fossil *Ammonites* (*Schloenbachia*) *inflatus* was found by Theobald near Mai-i, in the beds to which he gave the name of Mai-i Group.

**Distribution.**—The country where the Mai-i Series is developed is very wild and uninhabited and hence its boundaries can be only conjectural. The rocks are considered to extend from the Kyaukpyu district in lat. 19° 30′ N. as far as Kyeintali on the coast in the south, covering a distance of ninety-four miles as the crow flies. As for their extension south of Kyeintali nothing is certainly known. Theobald was inclined to think that some of the altered rocks and outcrops of limestone met with between Kyeintali and Cape Negrais might be of Cretaceous age, rather than Nummulitic, and he provisionally grouped these rocks with the Negrais.

**Lithology.**—The rock containing *Ammonites* (*Schloenbachia*) *inflatus* is an argillaceous limestone of a light cream colour with a somewhat speckled appearance from the dissemination in it of sublenticular crystalline particles, some of which may possibly be of foraminiferal origin. It is very homogeneous in texture, occasionally seamed with calcite and has a conchoidal fracture. This limestone is met with in several places, and at one locality, *e.g.* four miles south-south-west of Mai-i, it is burnt for lime. Associated with this group is another peculiar rock which may be used to trace its extent. It was first observed by Theobald, about two and a half miles north-east of Kyeintali, and consists of a greyish, rather argillaceous sandstone which sometimes exhibits a pisolitic structure. Small globular concretions of carbonate of lime and iron, rarely

[1] *Rec. Geol. Surv. Ind.* vol. xxiv, p. 98.

exceeding the size of a pea, are disseminated in the rock. On decomposing, these concretions leave holes containing a little powdery oxide of iron and impart to the earthy sandstones the appearance of an amygdaloidal trap. According to Theobald this very remarkable rock occurs in several places between Kyeintali and Mai-i. East of the latter place the Mai-i beds attain a great thickness, though some of them may belong to the older series. The prevailing dip is east-north-east, and the rocks are mainly hard, massive sandstones with some dark shales interspersed in them. The shales contain flat concretions of blue and pale grey limestone, rarely more than six inches across and from one to two inches in thickness. No fossils have yet been discovered in these beds.

## Upper Cretaceous Rocks, Ramri Island.

Lately Dr. Cotter, using a description by the late E. Vredenburg, has recorded the occurrence of a new species of ammonite, namely, *Acanthoceras daviesi* from Ramri Island. This ammonite belongs to the group of *Acanthoceras coleroonense* and is particularly closely allied to *Acanthoceras footeanum.* The latter occurs in the middle division of the Utatur beds and is, therefore, typically Cenomanian in age. In the present state of our knowledge the typical examples of the group of *Acanthoceras coleroonense* belong mainly to the Cenomanian, and according to Vredenburg this may also be taken as the age of the beds containing *Acanthoceras daviesi.* No Upper Cretaceous rocks were hitherto known from Ramri Island, and Dr. Cotter added that it would be interesting to know whether there is an unconformity between the Cenomanian and the Eocene rocks in Ramri Island or not.[1]

## Negrais Series.

The term Negrais Group was originally applied by Theobald to distinguish " a series of beds stretching northward from Cape Negrais along the Arakan range and coast . . . and regarded as probably embracing the lowest beds of the

[1] *Rec. Geol. Surv. Ind.* vol. lxvi, 1932, pp. 255-256.

Nummulitic group." Subsequently, however, he extended the application of the term to embrace all the rocks which were older than the Tertiaries and newer than the Axials met with in this district. In the absence of fossil evidence it is indeed difficult to say whether these beds should be referred mainly to the Eocene or to the Cretaceous.

**Distribution.**—The Negrais rocks extend from the Prome district in the north to Cape Negrais in the south, and occur on both flanks of the Arakan Yoma. Their junction with the Eocene rocks is marked by a fault, and their relations with the Axials are not clear, though there seems to be a gradual passage between the two.

**Lithology.**—The Negrais rocks show a very marked variation in their constitution. In some places they are composed of flaggy and massive sandstones which show moderate dips and very little alteration, while in others they are composed of highly altered shales and sandstones; at times the sandstone is converted into a cherty rock seamed with silica. In the Henzada and Bassein districts the Negrais Series was observed by the writer to consist of yellowish and greyish sandstones, quartz grits and highly indurated shales, which become very hard and slaty in places. Black shales are very common, sometimes with carbonaceous markings, which are so characteristic of the Nummulitic sandstones, described below. Bands of limestone and conglomerate are intercalated in the sandstone and shales.

**Metamorphism and Silicification.**—The series, as a whole, is highly indurated and sub-metamorphosed and is locally much folded, crumpled, bent and contorted. Acute synclinal and anticlinal flexures are not uncommon, while in places overfolding and thrust-planes on a small scale are also observed. Injections of compact and extremely fine-grained siliceous and cherty beds occur and sometimes limestone is entirely replaced by these siliceous masses. These cherty beds are of inorganic origin, as their sections, when examined under the microscope, did not reveal the presence of any organisms. Theobald [1] believed that this replacement was brought about by siliceous springs, the activity of which, according to him, still continues

[1] *Mem. Geol. Surv. Ind.* vol. x, 1873, pp. 118-119.

even at the present day. He stated that nowhere is the variable lithology of these rocks better displayed than along the coast immediately north of Cape Negrais. Below the point where the Ywot-pa stream falls into the sea, beds containing crushed carbonaceous trunks and branches show gentle dips varying from 10° to 40°. Nearer Negrais a thick series of dark shales, with subordinate beds of cherty limestone, crops out, showing signs of having undergone great mechanical stresses as well as chemical alteration. "The latter is displayed in the numerous veins of fibrous calcite and fibrous quartz which traverse the rock. . . . Some of the shales, where the veins are most numerous, are of a deep black colour and very hard and glossy. A little nodular soapstone is also found scattered here and there, and the occurrence of this mineral, together with its invariable associate, the fibrous vein quartz, points to this being a focus for that peculiar metamorphism, which has so generally affected this group."

As described in detail in a later chapter, the last phase in the igneous activity of the peridotitic masses in the Arakan Yoma consisted of the action of circulating waters containing silica, iron, lime, etc., in solution. It is these magmatic waters which brought about the so very widespread serpentinisation and silicification of the ultrabasic rocks. The serpentine masses show evidence of silicification, and veins of chalcedony sometimes form a network. It was noticed by the writer in the field that the Negrais rocks show greater alteration near the serpentine masses, and sometimes the former have been altered to typical chlorite and talc schists. The rocks have doubtless undergone great dynamic alteration, the effects being augmented by the peridotitic intrusions and the activity of thermal waters. Theobald states that he did not remark the siliceous beds to be so prominent as on the east of the range. This confirms the above statement that, as the peridotitic intrusions were mainly confined to the eastern limb of the Arakan Yoma, the magmatic waters were not available on the west to cause so much silicification as on the east.

**Fossils.**—Specimens of a few badly preserved *Vicarya* sp. were found by Murray Stuart in the Henzada district, from a shaly bed, about nine miles west of Myinwadaung.

### Cardita beaumonti Beds (Axial Series and Chin Shales).

It was noted above that part of the Axial group of Theobald and the Chin Shales of Noetling may be of Cretaceous age. The former had grouped the *Cardita* beds with his Upper Axials, but fossils from this bed examined by Mr. G. H. Tipper [1] have been shown to consist of fairly well preserved *Carditæ* and some poor gastropods (*Turritella*, etc.). The former comprise the well-known species *Cardita* (*Venericardia*) *beaumonti*, a form characteristic of beds in Sind and Baluchistan, which Vredenburg regarded as of Maestrichtian to perhaps Lower Danian in age.

### General Conditions during the Mesozoic Era.

It is very difficult to trace the changes in the distribution of land and sea in the Mesozoic era, but it is evident that the extensive Permo-Carboniferous sea occupying the Shan plateau, etc., had shrunk considerably soon afterwards, and extensive land conditions were prevalent in the early epochs—Bunter and Keuper—of the Mesozoic era. A restricted sea existed in the Rhaetic, Jurassic and Cretaceous periods, and most probably there was a marine transgression during Upper Triassic times. This sea disappeared finally from the eastern region covering the Shan plateau, etc., at the close of the Cretaceous period.

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[1] *Rec. Geol. Surv. Ind.* vol. xxxv, 1907, p. 119.

C.G.B.

## CHAPTER XXI

### TERTIARY SYSTEMS

The Tertiary era, as elsewhere in India, is the most important in the physical and geological history of Burma. It was during these ages that a very great portion of land, as explained in the sequel, was built up and the present configuration of the country was acquired. The end of the Cretaceous or the beginning of the Tertiary saw an era of earth-movements, which changed the whole geography of what now constitutes the province of Burma. It was at this time that the old continent of Gondwana Land broke up and the geosynclinal areas of the Shan plateau and the Arakan Yoma were lifted into land masses. The outburst of igneous intrusions along the whole length of the Arakan-Naga region on the west and the granitic intrusions on the east, as explained elsewhere, was obviously connected with these movements.

As remarked above, almost the whole of Burma, including the Shan plateau, was under the sea, and sedimentation was going on until the close of the Mesozoic era. It was in late Cretaceous times that the Shan plateau and the Arakan-Naga region were upheaved, and the latter constituted a low, narrow barrier between the areas of deposition on the east and west respectively. On either side of the barrier there existed a gulf which was gradually silted up in Tertiary times (see Fig. 16). Work by Cotter, Bion and others along the eastern foot of the Arakan Yoma has revealed the presence of a conglomerate at the base of the Eocene, and this conglomerate forms a very well-marked horizon. From its presence Dr. Cotter argues the existence of a coastline in Lower Eocene times near the present foot of the Yoma. In brief, the Tertiary history of the Central Belt of Burma has been the infilling of the Burmese gulf by

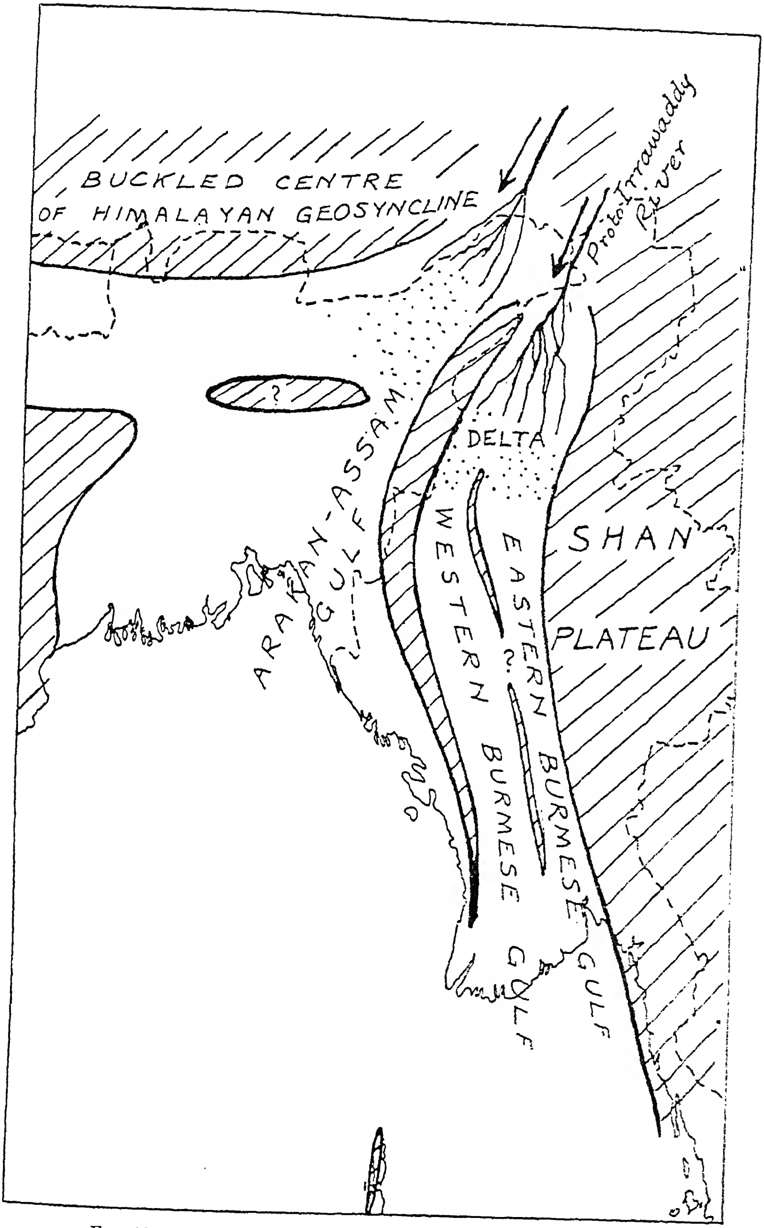


FIG. 16.—Showing the Burmese and the Assamese Gulfs in the early Tertiary period, with the position of the mouths of the Irrawaddy and the Brahmaputra rivers. (*After L. D. Stamp.*)

river-borne sediments from the north and by marine sediments in the south.

As a result of this deposition an unbroken series of Tertiary beds from the Eocene to the end of the Pliocene occurs in the Central Belt of Burma, including the eastern part of the Arakan-Naga region. Deposits belonging to the same period occur on a small scale in the rugged, much broken country bordering the western slopes of the Arakan Yoma, which were apparently laid down in the "Assamese gulf," referred to above.

**The "Burmese Gulf"—a Geosyncline.**—The Burmese gulf formed a geosynclinal area similar to the great Himalayan geosyncline. This geosyncline was gradually subsiding throughout the whole of the Tertiary period while the adjacent Arakan Yoma was an ever-rising geanticline. Gradually the head of the gulf filled up and became land, while the sea receded to the south. The fluviatile and deltaic sediments kept continually advancing towards the south. The area of subsidence had also apparently shifted to the south, and according to Dr. Cotter, it is not at all improbable that the present Gulf of Martaban constitutes the remnant of the old geosynclinal area. This sinking of the sea-bottom permitted the accumulation of a vast thickness of sediments. The following figures as given by Dr. Cotter [1] indicate, at least approximately, the total thickness of the Tertiary deposits:

| | |
|---|---|
| Pliocene - - | 6,000 feet |
| Oligocene - - | 4,500 to 5,000 feet |
| Miocene - - | 8,000 ,, |
| Eocene - - | 22,600 to 36,000 ,, |

These enormous deposits were laid down by the rivers draining the lands to the east, north and west of the gulf, and the present river system of the Irrawaddy is only a remnant of the vast river systems of the Tertiary period.

According to Dr. Cotter, from a study of the fossil contents of these formations, it appears that in all probability none of these deposits were laid down in water with depths exceeding 200 fathoms: it follows obviously that there must have been

[1] Cotter, G. de P., "The Geo-tectonics of the Tertiary Irrawaddy Basin," *Jour. and Proc. Asiatic Soc. Bengal*, N.S., vol. xiv, 1918.

continual subsidence in the Irrawaddy basin from the Lower Eocene right down to the end of the Tertiary era in order to allow of these deposits being laid down. Otherwise the sea must have silted up and become dry land at a very early period. Again, the rate of deposition and sinking did not go on without interruption, but there were many periods when the rate of subsidence was faster than sedimentation, as when such comparatively deep-water deposits as the Yaw Shales and Padaung Clay were laid down over shallow-water deposits such as the Pondaung and Shwezetaw Sandstones respectively. At other times sedimentation was faster than the rate of subsidence of the sea-bottom. In the latter case shallow-water deposits with very local unconformities [1] resulted. These local unconformities doubtless indicate the emergence of land from the Tertiary sea, or at least contemporaneous denudation by wave and current action. This cannot be regarded as indicative of upheaval, but merely as a retardation of subsidence, so that the sediments had time to fill up the sea locally, giving rise to red earth beds and bands of conglomerate, coal seams, remains of land vertebrates, etc.

**Regression and Transgression of the Sea.**—The close examination of these deposits reveals the interesting fact that they are entirely marine in the south, with the exception, however, of the topmost layers. On the other hand, farther north, there is a constant alternation of marine and continental deposits in the lower parts, while the upper part is either of brackish water, fluviatile, deltaic or entirely terrestrial origin. This is but natural in a sea whose level was constantly fluctuating. When the deposits accumulated at a rate faster than that of subsidence the sea receded, but when there was subsidence again it advanced. So there was a recurrent transgression of the sea during this period, and this is well supported by the occurrence of wedge-shaped marine strata in the midst of beds of continental type (see Fig. 17). As stated by Dr. Cotter, in every section from the Pondaung sandstone upwards there is a change horizontally along the strike, when traced from Minbu to Pakokku, from marine to fluviatile and red earth beds.

[1] The word unconformity is used to denote here the interruption of sedimentation.

Further, sometimes certain beds or series are absent from some areas, e.g. in the neighbourhood of Ngape, and this phenomenon is explained by Mr. Clegg as due to an overlap brought about by marine transgression in this area.

"**Buckling.**"—The Tertiary basin was subject also to buckling, which resulted in the deepening of the sea. An effect of buckling is seen in the overlap of certain beds when traced from the margin towards the centre. That is to say, normally two beds are in direct and conformable superposition;

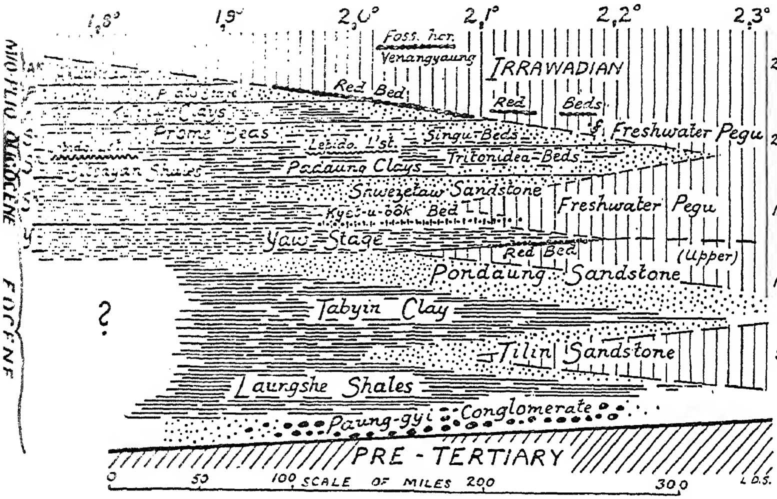


FIG. 17.—Diagram showing relationship of the Tertiary Rocks of the Burmese Gulf (*L. D. Stamp.*)

locally the lower bed may be absent and the higher bed may be seen resting on some older strata, owing to the effect of the slight folding and consequent denudation just prior to the deposition of the higher bed.

**Nature of the Deposits.**—In the south, sandstones, shales and limestones constitute these deposits. But in the north there frequently occur fluviatile and deltaic deposits in the midst of the marine sandstones, etc. False or current-bedding is noted often: in one and the same bed coarse and fine-grained materials occur. Again, in the north, it is only the lower part of the succession that is compact and shows any trace of bedding; the

upper horizons are composed mostly of incoherent sands and gravels.

**Fauna.**—The Tertiary deposits of Burma are noted for the wealth of their fossil contents. Marine invertebrate shells are prolific in many beds, gastropods being the most common, and many of the species are unknown elsewhere. There is no dearth of vertebrate remains: there occur at different horizons reptilian and mammalian fossils. The invertebrates bear less resemblance to those of India, but are largely akin to those of the Malay Archipelago.

**Tectonics.**—The eastern junction of the Tertiary rocks is marked by a main boundary fault along almost the entire margin of the Shan plateau. In several cases, where it has been examined, the junction between the Tertiary and the pre-Tertiary rocks on the eastern side of the Arakan Yoma is also faulted. The writer observed this faulted junction between the Negrais Series and the Nummulitic Sandstone Series in the Henzada and Bassein districts very clearly. Dr. L. Dudley Stamp postulated that it is quite possible that a great line of dislocation exists between the two—the Arakan Yoma and its foothills—and if this were the case the Tertiary region or the Central Belt of Burma constitutes a rift valley.

The Tertiaries have been folded into anticlines and synclines and faulted extensively. The different periods during which earth movements affected the deposits agree very closely with the periods during which the Himalayas were upheaved. Throughout the whole period the Arakan Yoma was also rising, as seen by the general easterly dip of the beds and also by the occurrence of conglomerate beds at its eastern margin. The first phase of this upheaval took place during the late Cretaceous or towards the commencement of the Eocene period. This resulted in the folding and crumpling of the pre-Tertiary deposits of the Arakan-Naga hills and the elevation of the long narrow strip of land in between the "Assamese and Burmese gulfs," forming the central core of the Arakan Yoma. This earth movement, as explained later, was attended by tremendous igneous activity, as shown by the numerous outcrops of serpentine along the whole length of the Arakan-Naga hills. The second phase, which took place probably during the middle

Miocene period, was responsible for the further upheaval and contortion of the Arakan Yoma and the formation of a ridge of land on the site of the Pegu Yoma. The final phase was post-Pliocene; it raised the Arakan and the Pegu Yomas to almost their present level and drove the Burmese gulf farther southward. It may safely be said that the present configuration of Burma was formed only during post-Pliocene times. Again, vulcanicity on an extensive scale manifested itself at various centres (for full details see chapters on "Igneous Activity").

With regard to the small anticlines in the basin it may be noted that they are not all of the same age. The Pondaung Range, which is over 200 miles long and rises to a height of over 4,000 feet, is undoubtedly pre-Irrawaddian, or may be even lower Tertiary, as in the Maw valley near Tilin, where deposits of gently dipping Maw gravels, a local facies of the Irrawaddians, rest upon the upturned edges of the Lower Eocene with strong unconformity and discordance. The folds of Yenangyaung, Yenangyat-Singu and Minbu, according to Dr. Cotter, are of an age not earlier than Irrawaddy, as the Pegu beds had undergone comparatively little folding before the Irrawaddians were deposited. That would indicate that the Pegu beds were horizontal and unfolded at the time the Irrawaddian beds were being deposited.

**Economics.**—Economically the Tertiaries are the most important deposits of Burma, as they contain valuable petroliferous horizons, and consequently they have been studied in great detail during recent years. Coal-seams occur in the Eocene and Oligocene strata, but as yet they have not proved to be of much economic value. Amber in the Eocene deposits and jadeite in the Tertiary conglomerates are found associated with these deposits. The Tertiary sandstones provide good building material, road metal and ballast for the railways.

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## CHAPTER XXII

### THE EOCENE SYSTEM

A BELT of Eocene rocks extends from the Dutch East Indies through the Andaman and Nicobar islands to Upper Burma. The term "Nummulitic" or Eocene group was first applied by Theobald to designate the Eocene rocks in Burma; but he drew, as shown in the sequel, his upper limit too high, and included in it some limestones with *Lepidocyclines* of Oligocene age. There is also difficulty in correlating the beds of Upper Burma with those of Lower Burma, primarily on account of the difference in the facies of the deposits of the two regions, and secondarily on account of the imperfect knowledge of the Eocene of the latter area as compared with the detailed knowledge of it in Upper Burma. Hence the Eocene geology of Lower and Upper Burma has to be dealt with separately.

#### Andaman and Nicobar Islands.

The main islands of the Andaman and Nicobar group are composed largely of Eocene rocks. In the North and Middle Andaman islands the prevailing rock is a conglomerate, while in the South Island a sandstone with clays is the chief rock. They rest unconformably on, and contain pebbles derived from, the underlying rocks, which are probably Cretaceous and comparable with the Axial Group of the Arakan Yoma. The coarse varieties of the conglomerate contain well-rounded pebbles ranging up to several inches in diameter, though the harder quartzite pebbles are somewhat angular. The pebbles include chiefly white and yellow quartzites with red jaspers, serpentine, volcanic rocks and grey quartzitic sandstones. The matrix of the conglomerates is often arenaceous, but sometimes argillaceous,

of dull-green colour, probably derived largely from the serpentines. The sandstones grade into the conglomerates and vary considerably in texture.

The fossils present are some nummulites, a poorly-preserved *Turritella*, some lamellibranch fragments and spines of echinoids. The nummulite belongs to the group of *Nummulites atacicus* (*biarritzensis*). According to G. H. Tipper it is identical with the Indian species which has been identified as *N. atacicus*. The *Assilina* has been recognised by him to belong to the type *Assilina granulosa*, characteristic of the Lower Eocene of Sind, Baluchistan and the Punjab, and denotes an horizon equivalent to the Laki beds of those regions of western India. In passing, it may be noted that the deepest water in Eocene times lay to the south, and the deposits of this age are represented by limestones in parts of Sumatra and Java.

## The Eocene Deposits of Lower Burma.

**Distribution.**—The Eocene deposits of Lower Burma, from the Thayetmyo district southwards, are confined entirely to the eastern foothills of the Arakan Yoma. They occur as a long, elevated band, with varying breadth, between the pre-Tertiary altered rocks constituting the core of the Arakan Yoma and the newer Tertiary deposits on the western banks of the Irrawaddy. On the eastern side of the Arakan Yoma there is a marked change in the physical configuration of the ground with the eastern boundary of the Nummulitic group, which builds higher rugged hill ranges, as contrasted with the low undulating country occupied by the later Tertiaries. A few miles west of Thayetmyo the outcrop has a maximum breadth of 17 miles, which gradually diminishes as we proceed southwards until west of Prome it is not more than 6 miles across. Near Myanaung in the Henzada district it again attains considerable breadth, although much obscured by a cover of laterite and gravel. But west of Bassein the Eocene rocks reappear again and extend to Cape Negrais.

**Relations with the Underlying Strata.**—The beds composing the Eocene system possess a general easterly dip in the northern portion of the area, but in the south the precise inclination of

the deposits is difficult to state, as they appear to merge at the base into the altered Negrais beds. Murray Stuart believes that there is a marked unconformity as the Eocene rocks successively overlap all the older formations as they are traced from the south to the north. However, it is now agreed that they are faulted against the pre-Tertiary rocks.

**Lithology.**—Sandstones, shales and limestones form the Eocene deposits of Lower Burma. In the Thayetmyo district, near Thambula, Theobald described the following section in descending order :

| | |
|---|---|
| 4. Nummulitic limestone - - - - | 10 feet |
| 3. Shales and sandstones ; shales occasionally nummulitic - - - - - - | 658 ,, |
| 2. Massive sandstones, with some shales and much soda efflorescence in places - - | 328 ,, |
| 1. Shales and sandstones, the shales with carbonaceous markings - - - - | 227 ,, |
| | 1,223 ,, |

The sandstones, which are compact though not very hard, are of a yellowish or greyish colour. They are often highly argillaceous. In some places they are well bedded and often traversed by joints, as a result of which they fall into polygonal blocks. In others, on account of their compact, thick-bedded earthy nature, they form peaks consisting of smooth bosses of naked rock, weathering in much the fashion of granite, in tor-like masses. Small nodular concretions, three to fifteen inches in diameter, having a sub-crystalline texture, also occur sometimes, and impart a conglomeratic aspect to them. They pass into quartz grits and indurated conglomerates, especially towards the base. Some of the sandstones, grits and conglomerates contain fragments of volcanic rocks and serpentine. Towards the south some of the argillaceous sandstones which occupy a high position in the system are quarried for the carving of the images of Buddha, and are locally known as "*andagu-kyauk*."

Shales occur associated with and above the sandstones. Those associated with the sandstones contain impressions of

leaves, which are in too bad a state of preservation to permit of their identification. Broadly speaking, the Eocene shales are mostly bluish in colour, while an indigo colour is not uncommon, though not often readily recognised as a result of weathering. They are ill-bedded, unctuous, tough and clunchy. In places they are calcareous. Although the shales are eminently suited for the preservation of organisms, with the exception of a few cycloidal fish scales, they have yielded no useful fossils.

Limestones, containing *Nummulites* (*N. vredenburgi*), occur as bands in the sandstones. They are also associated with the shales and overlie them too. The limestone overlying the shales is not of very great thickness, nor is it continuous throughout the area where the Eocene outcrops occur. This discontinuity is due partly to denudation and partly to thinning out, when it is seen as small lenticular bands in the shales. Generally, this limestone, wherever it occurs, forms the topmost bed of the Eocene system, though some of it is also believed to be of Oligocene age. Theobald mapped as Nummulitic limestones certain limestone bands with *Lepidocyclina*, which occur in the lower part of the Pegu, and so has drawn the upper limit of the "Nummulitics" too high. In the Henzada and Bassein districts the system consists mainly of sandstones. The colour of the fresh rock is bluish-grey, but on weathering various shades of yellowish, greyish, greyish-yellow, and reddish tints are assumed. The sandstones towards the base pass into quartz grits. At a few places these sandstones include beds of shale which enclose seams of pure and friable coal. The shales have been converted into schists with the formation of graphite, where they have been invaded by serpentine. Carbonaceous markings are common, but no other fossils except *Nummulites* sp. have been found.

**Coal.**—In the Henzada district outcrops of coal occur in the basal Eocene sandstones. The chief outcrops of importance are at Posugyi, Kywezin, Hlemauk and Kyibin. In all these places the thickness of the seams is very meagre; only the Kywezin seam is 10 feet thick, but the coal there is very friable, greatly crushed and contorted. They are of little economic value on account of their high dips and low carbon content.

**Age.**—Mr. Datta collected *Nummulites atacicus* and *Assilina granulosa* from the eastern Arakan Yoma. Later Sethu Rama Rao collected specimens of *N. atacicus* from the same horizon, but from the north of the region, which Mr. Datta worked over, when crossing the Arakan Yoma. The list of localities where these fossils were collected is given in the *Records of the Geological Survey of India*.[1] These fossils are undoubtedly of Laki age, and are underlain by Cretaceous limestone containing *Cardita beaumonti*. Dr. Cotter says that if the lines of strike are continued northwards the part which he mapped as Lower Eocene would correspond with these Laki beds. Thus we apparently have in this part of Burma the equivalents of the Kirthars, Lakis and Pab Sandstones of India.

## The Eocene Deposits of Upper Burma.

The Eocene deposits of Upper Burma, *i.e.* in the country north of the Thayetmyo district, have been classified as follows (see also Fig. 17):

6. Yaw shales.
5. Pondaung sandstones.
4. Tabyin clays.
3. Tilin sandstones.
2. Laungshe shales.
1. Paunggyi or Shwelegyin conglomerates.

**Paunggyi or Shwelegyin Conglomerates.**—The base of the Eocene of Upper Burma is composed of a series of beds, mainly conglomerates with some grits and sandstones. These conglomerates, on account of their typical development near the village of Paunggyi in the Minbu district, have been designated the Paunggyi Conglomerates. In the Pakokku district they are called the Shwelegyin Conglomerates. Their total thickness is estimated by Cotter at 2,000–4,000 feet. They are unaltered when compared with the underlying, highly folded and cleaved shales or phyllites (of unknown age) known as the Kanpetlet schists. The pebbles composing the conglomerates are of schists,

[1] *Rec. Geol. Surv. Ind.* vol. xli, 1912, p. 322.

phyllites and gneisses; the first two were probably derived from the Kanpetlet schists, while the last appears to have been derived from very old gneisses.

**The Laungshe Shales.**—The Paunggyi or the Shwelegyin conglomerates are overlain by a thick series of shales called the Laungshe Shales, whose thickness according to Dr. Cotter ranges from 9,000 to 12,000 feet. Examination of the fauna, including *Operculina* and *Orthophragmina*, by E. Vredenburg shows that these shales correspond essentially to the Laki (Libyan) stage, but extend down also to at least the uppermost zone of the Upper Ranikot of Western India. Some of the fossils present a late Cretaceous aspect, representing possibly survivals in the early Eocene gulf.

**The Tilin Sandstone.**—The Laungshe Shales are overlaid by an arenaceous group called the Tilin Sandstones, which are marine in the south and brackish or fresh water in the north. Its thickness in the north is estimated roughly at 5,000 feet; but this gradually dwindles as the bed is traced southwards, when it finally disappears. This attenuation from an estimated thickness of up to 5,000 feet in the north to nothing in the south probably accounts for the huge thickness claimed for the Laungshe Shales in the south. Dr. Cotter refers to these sandstones as containing small nummulites and apparently of Lower Eocene age, but the term is still not precisely defined. The Tilin Sandstone and the underlying shales dip very steeply.

**The Tabyin Clays.**—The Tabyin clay group is characterised by the predominance of greenish or olive-coloured rubbly or conglomeratic shales. Interbedded with them are sandstones, which in places contain marked septaria. The latter are yellowish-brown on the outside, but dark grey in the centre when broken across. They are seamed with cracks filled with calcite. Coal seams are of constant occurrence in the Tabyin Clays of the Pondaung range, but carry only fragmentary plant remains. The probable maximum thickness of the group is 5,000 feet. This group also, just like the previous ones, is continental in the north and marine in the south. In the south fossils like *Arca* and nummulites are found. The latter include the characteristic fossil of the lower division of the Middle Kirthar period, viz., *Nummulites vredenburgi.*

**The Pondaung Sandstones.**—This group has been so named on account of its typical development in the Pondaung range. Between the Tabyin Clays and the overlying Pondaung Sandstones there is no perceptible break, as the former passes upwards by insensible gradations into the latter. In the type area examined by Dr. Stamp, the lower part of the group comprises a somewhat monotonous series of greenish sandstones with bands of conglomerate and greenish clays or shales. The pebbles constituting the conglomerate bands consist of schists and gneisses, as well as plutonic, hypabyssal and volcanic rocks. The upper part, however, includes some very remarkable beds of purplish, pale greenish or variegated clays. Under different conditions of weathering this group presents very different appearances. By subaerial weathering (as seen in river sections) a greenish tint is developed, while atmospheric weathering imparts a yellow colour.

This group is not less than 5,000 feet in thickness in the south and 6,500 feet in lat. 22° 5′. It is characterised by the constant occurrence of fossil wood; in the lower part it is always carbonised, and trees of considerable size may be traced in many of the beds of sandstone by their carbonised bark. At higher horizons the wood is partly carbonised and partly silicified. In the upper part the wood is always silicified, and is indistinguishable from the well-known silicified wood of the Irrawaddy Series. The upper portion is further characterised by the occurrence of coloured clays, which are mostly sandy. The predominant colour of the clays is either a reddish purple or a pale green. Usually the two tints are seen together, and an intermediate shade is afforded by a bluish purple. Dark brown iron nodules and calcite abound.

**Fauna.**—*Cardita mutabilis*, *Arca pondaungensis*, *Septifer* sp. *Corbula daltoni*, *Alectryonia newtoni* and marine gastropods occur in a fossiliferous conglomerate bed at the base of the group. The clay bed about the middle of the group has yielded only remains of *Cytheria*. The sandstone associated with these shales contain fairly well-preserved leaves, which appear in the main to be dicotyledonous. From the coloured clays in the upper part abundant reptilian remains, especially chelonian and crocodilian (*Crocodilus*) fossils, have been collected from these

beds in the Myaing township of the Pakokku district, as well as mammalian bones, and these, according to Pilgrim, comprise the following :

(*a*) **Perissodactyla:**

*Sivatitanops cotteri, S. birmanicum, S. rugosidens.*
*Eotitanotherium? lahirii.*
*Metamynodon cotteri, M. birmanicum.*
*Indolophus guptai.*
*Chasmotherium ? birmanicum.*

(*b*) **Artiodactyla:**

*Anthracohyus choeroides.*
*Anthracothema pangan, A. rubricae, A. palustre, A. crassum.*
*Anthracokeryx moriturus, A. birmanicus, A. ulnifer, A. bambusae, A. hospes, A. myaingensis.*
*Indomeryx cotteri, I. arenae.*

**Conditions of Deposition.**—As stated above, this group is distinctly marine in the south and continental in the north. This fact is substantiated by the occurrence of marine fossils like *Arca*, *Cardita*, and other marine forms in the south, and by the presence of fossil wood and mammalian remains in the north. Furthermore, a red bed resembling laterite and denoting terrestrial conditions is seen only in the north at the top of the group. When traced from the south to the north a gradual but clear change from marine to terrestrial conditions is well indicated. The greater thickness of the deposits in the north proves a regression of the sea from the north to the south.

**The Yaw Shales.**—The Pondaung Sandstones are succeeded by bluish-grey shales or clays, which on account of their marked development in the Yaw river sections have been termed by Dr. Cotter the Yaw Shales. This series is essentially a marine one, as seen from the fossils listed below, and is typically developed about lat. 21° 30′ N. and long. 94° 20′ E. ; northwards marine fossils become gradually scarcer and stunted and the deposits wedge out. These shales frequently contain very thin bands of impure, calcareous or septarian material. In some places, on one or both sides of the band, "cone-in-cone"

structure is developed, and the apices of the cones always point to the centre of the band. Large rounded septaria also occur, but they have not that characteristic cracking seen in the septaria of the Tabyin Clays. Towards the base of the Yaw Shales, as for example in the *chaung* just to the north-west of Gyat village, there occur thin bands simply packed with the teeth, vertebrae and scales of various species of fish. At intervals remarkable and distinctive bands of what may be called "phosphatic or fossil conglomerates" also occur. These are of about the same thickness as the septarian bands, and they have the same septarian material as matrix. Scattered or packed fairly closely throughout, are dark brown, often slightly lustrous pebbles about an inch in length. In some cases they seem to be merely pebbles of shale, slightly altered on the outside; in other cases they appear to be phosphatised excreta or "coprolites." When traced northwards the Yaw Shales become attenuated, and pass upwards into the overlying Shwezetaw Sandstones. But the lower boundary, *i.e.* with the Pondaung Sandstone, is well marked. Rolling of strata is also seen in the Yaw Shales exposed in the Yaw river section.

**Fauna**.—Foraminifera : *Nummulites*, especially *N. yawensis*, *Orthophragmina omphalus*, and *O. sella*, *Gypsina globulus* and *Operculina* sp. Of these *N. yawensis* is a new species allied to *N. aturicus* and *N. scaber*.

Lamellibranchiata : *Solen manensis*, *Corbula subexarata* var. *lituus*, *Corbula paukensis*, *Meretrix* (*Callista*) *yawensis*, *Meretrix agrestis*, *Sunetta yethama*, *Venus pasokensis*, *Tellina nanggulanensis*, *Tellina* (*Arcopagia*) *tazuvensis*, *Tellina salinensis*, *Cardium kanleanum*, *Cardium thetkegyinense*, *Cardium subfragile*, *Chama* sp., *Lucina yawensis*, *Pinna* sp., *Ostrea minbuensis*, *Leda silvestris*.

Gastropoda : *Velates schmideliana*, *Cyprædia birmanica*, *Gosavia birmanica*, *Aulica birmanica*.

**Relationships of the Fauna.**—Of the fourteen new species of lamellibranchiata from the Yaw Shales some are related to those found in the Paris basin and to those in Java and Borneo. Only one species, *Corbula* (*Bicorbula*) *subexarata*, is found in

the Kirthar of India. According to Dr. Cotter two facts stand out clearly: firstly, the absence of any close similarity to the fauna of the Kirthar of India; and, secondly, the absence of any species common to the fauna of the Pegu beds as described by Noetling. However, the specimens described hitherto from the Kirthars come mainly from limestones, and the difference in facies perhaps accounts for much of the dissimilarity. Moreover, the Yaw Stage is slightly newer than the Kirthars. From fossil evidence Cotter has concluded "that Burma, Sumatra, Java and Borneo constituted in Eocene times a palaeontological province apart from Sind-Baluchistan, and that in the latter area the relationships are closer to the Egyptian Eocene."

In addition to the above there occur also corals and bryozoa, besides striated and serrated spines (cf. *Mylobites* of Noetling), phosphatised excreta and crustacean fragments (? *Callianassa*).

**Lateral Change of Facies.**—The Yaw Stage shows lateral changes in its facies. It is mainly a marine stage, as seen by occurrence of nummulites and other marine mollusca, but they become scarcer and stunted and the deposits wedge out as they are traced from the south to the north. In the north of Minbu it contains coal seams, and its facies suggests probably shallow water conditions close to the coastline. In the south of Pakokku the abundance of *Pleurotomidae*, *Volutidae*, and of *Conus* indicates deeper water. In the north of Pakokku it becomes a shallow water facies again, while in parts of the Myaing township it is almost fluviatile.

In the north the occurrence of bone beds packed with the vertebrae of fishes is generally connected with the invasion of the sea. It has been noted above that there was a regression of the sea from the north to the south during the period of deposition of the Pondaung Sandstones. The occurrence of the vertebrate fossils and their association with phosphatised excreta and crustacean fragments go to show that there was an invasion of the sea from the south to the north during the deposition of the Yaw Shales. It is on account of this that the thickness of the deposits of this stage is considerable in the south, while it gradually attenuates in the north and passes upwards into the Shwezetaw Sandstones of the Pegu system. These deposits, as the result of E. Vredenburg's latest work,

have been regarded as of Upper Eocene age, corresponding with the Nanggulan Series of Java.

### Kyet-u-bok Bed.

Near the deserted village of Kyet-u-bok there occurs a fossil bed which is regarded by Cotter as the topmost bed of the Eocene system, although Stamp regards it as the basal bed of the Pegu Series. The bed containing the fossils is a limestone conglomerate in which the pebbles are mostly of quartz. It does not lie with any marked unconformity on the underlying beds. *Nummulites yawensis*, *Orthophragmina omphalus*, *Operculina* sp. and *Gypsina globulus* occur. The associated mollusca include species common to the underlying Yaw Stage, notably *Velates orientalis*.

**Structure of the Eocene Deposits.**—The Eocene deposits, on the whole, are believed to be quite conformable, and there is no discordance of dip at any part, although there has been interruption of sedimentation at many horizons giving rise to local unconformities. On the other hand, in some places, *e.g.* in the Ngape area, certain strata are absent owing to an overlap from this area northwards and westwards brought about by the gradual sinking of the local basin. It may be said, however, in passing, that the Eocene and the overlying deposits have been thrown into folds, and that the former occur as inliers in the latter, and sometimes they are faulted, occasionally along the crests of anticlines and synclines.

**Correlation.**—Fossils are abundant, and well preserved as a rule in the Yaw Shales, and are not uncommon, although ill preserved in the Pondaung Sandstones. The four sub-divisions below the latter have hitherto been found surprisingly barren of fossils; a few ill-preserved specimens have been collected, but nothing sufficiently good to warrant palaeontological description. It has been noted already that reptilian and mammalian remains occur in the Pondaung Sandstones besides marine molluscs. The *Perissodactyla* and *Artiodactyla* from these indicate an upper Eocene age. According to Pilgrim, "the Pondaung *Anthracotheridae* now appear to be certainly more primitive than those of the Lower Oligocene beds of

Egypt, while, on the other hand, they are more progressive than the *Helohyidae* of Mongolia, which are regarded as Middle Eocene. This affords strong confirmatory evidence of the Upper Eocene age of the Pondaung fauna, which Cotter maintained from stratigraphical considerations connected with his study of the invertebrate fauna of the overlying Yaw Stage. That they are at least as old as the Bartonian is rendered likely by the fact that the smaller forms referred to *Anthracokeryx* seem in some ways to be more primitive than the oldest European *Anthracotheres* of the type of *Haplobunodon* and *Lophiobunodon*, which have been regarded as upper Lutetian."

The foraminifera obtained from the Yaw Stage are *Nummulites yawensis*, *Orthophragmina sella* and *Operculina* sp. These are probably indicative of a Bartonian age. The gastropods and the lamellibranchs also indicate the same age. The presence of *Nummulites vredenburgi* in the Tabyin Clay shows its Middle Eocene age. The following table shows the age, thickness and important fossils of the different stages, as correlated with the allied formations of North-West India and North-Western Europe :

| Name of Stage. | N.W. Europe. | N.W. India. | Thickness in feet. | Important fossils. | Age. |
|---|---|---|---|---|---|
| Yaw stage. | Bartonian. | | 1,600–2,000 | *Nummulites yawensis*, *Orthophragmina sella*, *Velates* sp., *Cypraea elegans*. | Upper Eocene. |
| Pondaung sandstones. | Ledian. | | 3,000–8,000 | *Anthracohyus choeroides*, *Anthracohyus rubricae*, *Anthracohyus palustris*, *Anthracotherium pangan*. | Upper Eocene. |
| Tabyin clays. | Lutetian. | Kirthar. | 5,000 | *Nummulites vredenburgi*. | Mid. Eocene. |
| Tilin sandstones. | | | 2,000 or less to 5,000. | Small nummulites. | Mid. Eocene. |
| Laungshe shales. | Ypresian. | Laki. | 9,000–12,000 | *Operculina* sp. | Lower to Mid. Eocene. |
| Paunggyi or Shwelegyin conglomerate. | Landenian. | Ranikot. | 2,000–4,000. | *Orthophragmina* sp. | Lower Eocene. |

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# CHAPTER XXIII

## THE PEGU SERIES

### OLIGO-MIOCENE

THE term "Pegu Group" was first introduced by Theobald to designate an important group of deposits occupying most of the ground intervening between the Irrawaddy and the Sittang rivers, including both the low ground and the bulk of the Pegu Yoma. On the west of the Irrawaddy, this group outcrops for a long distance between the Eocene and the Irrawaddian beds and also occurs as inliers in the latter. Among the Tertiaries the Pegu Series is by far the most important, primarily because of the occurrence of oil-bearing horizons; and secondly because of the wealth of its well-preserved fossils which have enabled the group to be divided into a number of stages, etc. The Pegu Series is generally understood to embrace the Post-Eocene and pre-Irrawaddian deposits of Burma, and this is the sense in which Theobald propounded the name. However, Dr. Cotter has shown that Theobald's base of the Pegu group is vitiated in some cases when he included the *Lepidocyclina* beds in the Eocene. Further, the same author has alluded to the difficulty of drawing the boundary between the Mogaung sands, which were included by Theobald in his "Fossil Wood Group," or the Irrawaddy Series and the beds below. The group, treated as a whole, is distinctly marine in the south with the exception of the uppermost beds, while in the north it exhibits a thoroughly continental facies, and it was believed for a long time that the northern beds were of younger age than their marine equivalents in the south. Later researches, however, have shown that both of these facies are of the same age. L. D. Stamp has suggested that the marine facies of the Pegu Series, in the south, is usually divisible into three lithological groups

which transgress the time planes; but this view has not met with general acceptance and G. W. Lepper, on the basis of evidence obtained by Eames and other geologists of the Burma Oil Company, considers that the lithological and palaeontological stages are in remarkably close agreement. The classification according to Dr. Stamp is:

(3) An upper mixed sandy and shaly group including the Lower and Upper Prome beds of Theobald with the Kama Clay of Lower Burma; the upper sandy or mixed groups of the Thayetmyo and Minbu districts and the exposed Pegu rocks of the oilfields of Yenangyaung, Singu and Yenangyat (at least the higher beds). This group is described in detail in the sequel, pp. 242-244.

(2) A middle group of rubbly or sandy shales comprising the Sitsayan Shales of Lower Burma, decreasing in thickness northwards and passing into the Padaung Clays.

(1) A lower sandy or mixed group, comprising the Shwezetaw Sandstones of Upper Burma. This group becomes less marked southwards and eventually disappears.

Thus the Pegu Series becomes continental northwards in the Pakokku and Lower Chindwin districts, the Padaung Clay, the middle group, remaining marine for the greatest distance. Eventually, however, the whole of the Peguan becomes continental.

There has been considerable difficulty in correlating the beds observed at different places on account of the lateral variation exhibited by the same bed. However, the Pegu Series in the south has been divided on a palaeontological basis by Vredenburg into the following stages: [1]

| | |
|---|---|
| 6. Akauktaung Stage. | |
| 5. Pyalo Stage (?) sandstones, pebble beds, shales, about 1,500 feet, with *Ostrea latimarginata* - - - - - - | Burdigalian |
| 4. Kama Stage, shales and sandstones, about 1,500 to 2,000 feet, containing a rich gastropod fauna - - - - - - | Aquitanian |

[1] But see the modification proposed by Stamp mentioned below, p. 239. Stamp finds no evidence for the Pyalo Stage and has found a Kama fauna *above* the supposed Pyalo horizon.

| | |
|---|---|
| 3. Singu Stage, sandstones and shales, about 1,500 feet - - - - - - | Upper Nari |
| 2. Sitsayan Stage, or Padaung clay, principally shales, with subordinate sandstones, 1,500 to 3,000 feet, containing *Lepidocyclina*, *Schizaster* and *Heterosteginae* - | Lower Nari (Stampian) |
| 1. Shwezetaw Stage, mostly sandstone about 3,000 feet, with *Ampullina birmanica*, and *Batissa* sp. | |

Dr. Stamp's view as to the way in which the different palaeontological stages cross the lithological divisions is illustrated in

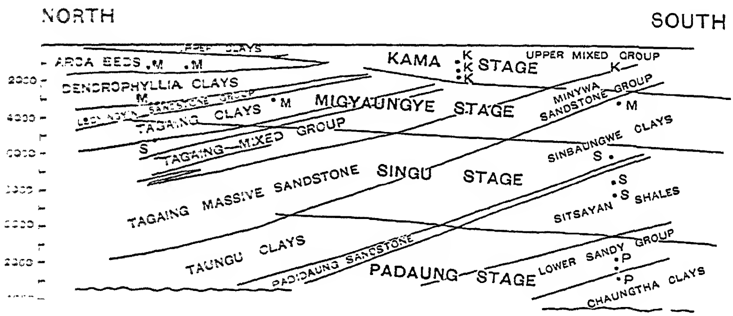


FIG. 18.—Diagrammatic section drawn approximately to scale, showing the variation in lithology in the Peguan of Central Burma and the way in which the palaeontological stages cross the lithological horizons. The section is drawn roughly from Minbu to Thayetmyo. (After L. D. Stamp.)

Fig. 18, but it may perhaps be stated that this view is at variance with that of the geologists of the Burma Oil Company.

**Shwezetaw Stage.**—In Lower Burma the basal Pegu beds are composed of shales forming the lower portion of the Sitsayan Shales of the Henzada and Prome districts. When these are traced northwards, *i.e.* towards Yenama and Ngape, shales and sandstones occur. The shales below the sandstones are usually unfossiliferous, but Dr. L. D. Stamp [1] has reported his discovery of an interesting fauna, a few hundred feet above the base of the Magyisan *chaung*, which included forms closely allied to, but specifically distinct from, species described from higher horizons

[1] It has been noted above that Stamp regards the Kyet-u-bok Bed as a basal conglomerate of the whole series, its Eocene fossils being derived.

of the Pegus. Farther north, the Shwezetaw Stage is represented by shallow water sandstones. These have been termed by Dr. Cotter the "Shwezetaw Sandstones" after the famous pagoda at the village of Payaywa in the Minbu district, where these beds are typically developed. In the Ngape area, the thickness of the Shwezetaw Stage has been estimated at nearly 3,000 feet. The lower part of this stage was examined by Dr. Stamp in the Pondaung range. Here they are fine-grained, soft sandstones which tend to form a very steep scarp slope conspicuous in local topography. A few hundred feet above the base of the sandstones a band of ferruginous conglomerate with pebbles of vein quartz, not exceeding one inch in diameter, occurs. False-bedding is the exception rather than the rule in this district, but away to the north—to the south of Mingin and possibly on a higher horizon—the beds become coarser, markedly false-bedded and conglomeratic bands of quartz pebbles are frequent.

Near the Yaw river the Shwezetaw Sandstones contain coal seams at Letpanhla and Tazu villages. The seams are thin and the quantity of coal available is very small; they are marred by frequent partings, making them expensive to work. Besides, the quality of the coal is very poor owing to the high percentage of moisture, the small amount of fixed carbon and the presence of excessive sulphur.

**Sandstones of the Shinmadaung area.**—To the north of Pakokku, in the Shinmadaung area, the Shwezetaw Sandstones containing *Ampullina birmanica* are faulted against newer beds. Here the total thickness, according to Vredenburg, equals or exceeds 3,000 feet. At this locality the sandstone is overlain by shales of the Sitsayan Stage. It is interesting to note the occurrence of contemporaneous volcanic intercalations.

**Fauna and Age.**—The Shwezetaw Stage is regarded as totally unfossiliferous in Lower Burma, though the finding of fossils by Vredenburg and Stamp has been noted previously. From the Ngape area *Vicarya* allied to, but apparently differing in ornamentation from, *V. verneuili*, fragments of *Ostrea*, *Ampullina birmanica* and *Cardita* cf. *mutabilis* have been obtained by Cotter. In the Pondaung range, the only fossils detected were logs of wood riddled with the borings of worms or lithophagous

molluscs and partly silicified. From the fossil evidence and its stratigraphic position between the undoubted upper Eocene and middle Oligocene, E. Vredenburg regards the stage as lower Oligocene (Lattorfian) in age.

**Sitsayan or Padaung Stage.**—In the Henzada and Prome districts this stage is represented by a thick deposit of shales. These are specially well developed near Sitsayan, 8½ miles above Prome on the Irrawaddy, which gives its name to the stage. They are exposed at several places along the boundary of the Eocene rocks and appear to overlie the latter conformably in the Prome district. Murray Stuart, however, considers the boundary an unconformable one. These shales, on account of their peculiar character, form rather level tracts of gently undulating country, but somewhat intersected by deep beds of streams in the banks of which they may usually be seen exposed. Good sections are comparatively rare, but Sir Edwin Pascoe writes that an observed section was estimated at close on 400 feet thick, though Theobald considered 800 feet would represent more approximately the total thickness of this stage. Stamp carefully measured sections south of Thayetmyo and found a thickness of 4,030 feet.[1]

The Sitsayan shale is a blue, somewhat clunchy clay, with very little appearance of bedding save towards its upper portion where sandstone courses begin to come in. When dried, it is of a pale colour, and cracks and falls to pieces spontaneously, a habit which depends probably on the homogeneous and purely argillaceous character and fine state of division of the material composing it. Occasionally irregular layers of fibrous marl or layers of hard yellow marl traversed by shrinkage seams or septaria with the cracks filled by carbonate of lime, occur. The bedding can be made out sometimes by the occurrence of the marls. The Sitsayan Shales are almost unfossiliferous although they are eminently suited for the preservation of organisms. Theobald did not obtain any fossils at all from any of the outcrops and he went so far as to suggest that the Sitsayan Shales are entirely devoid of them. However, Vredenburg obtained, close to the landing stage at Sitsayan, specimens of fish teeth and scales and shells belonging to the

[1] *Geol. Mag.* vol. lxii, 1925, p. 524.

genera *Corbula* and *Pecten* exhibiting the general facies of the fauna of the oilfields, but not sufficiently well preserved for a thoroughly specific determination. This stage is characterised by *Tritonidea martiniana*, and towards the higher part, as described below, calcareous bands with *Lepidocyclina theobaldi*.

**Lepidocyclina Limestone.**—Theobald included in his Nummulitic group a greyish pink limestone forming the crest of Tondaung, a hill about 4 miles south-south-west of Thayetmyo. He described it as having been brought up in the midst of younger strata by faulting. He included this limestone in his Nummulitic group under the impression that the fossils found in it were nummulites. Later work by Cotter has revealed that what Theobald mistook for nummulites were really lepidocyclines. According to Cotter "the Lime Hill then, may be Nummulitic in Theobald's original sense, although Oligocene, not Eocene; but unless it contains Eocene strata below the *Lepidocyclina* limestone, it must be placed entirely in Pegus in accordance with our revised system of sub-division. The strata below the *Lepidocyclina* limestone are described by R. Romanis [1] as containing coal seams in hard blue shale near the base of the exposed strata and on the south-west spur of the middle of the three hills which form the Myinmagyitaung (the Lime Hill being the easterly). The blue shale above the coal is full of vegetable remains and above this horizon the shales appear to be unfossiliferous, until the limestone capping of the hill range is reached. There is no evidence, therefore, that the shales are much older than the *Lepidocyclina* limestone. If we place the latter in the Padaung Stage, which appears most probable, then the shales below may perhaps represent the Shwezetaw Stage. The presence of coal seams would seem to suggest either the Shwezetaw sandstones or the Yaw Stage." Cotter further adds, "We may regard the Myinmagyitaung and Lime Hill, therefore, as containing in its upper horizons the equivalent of the Padaung Clays, *i.e.* the *Lepidocyclina* beds and beneath probably the Shwezetaw Stage, and possibly also the Yaw: but there are no fossils to indicate the age, and the evidence of coal seams is very unreliable."

[1] Romanis, R.: "Oil-wells and Coal in Thayetmyo." *Rec. Geol. Surv. Ind.* vol. xviii, p. 149.

**Padaung Clays.**—In Upper Burma, in West Minbu, there occurs a zone of clays, blue-grey in colour, containing a subordinate bed of grey limestone. They have been named by Cotter the Padaung Clays after the village of Padaung in the Minbu district. The thickness of these clays, according to Cotter, is perhaps 1,300 to 1,500 feet, the limestone band in the upper part having a thickness of 35 feet in one locality. The beds were regarded as Upper Nari in age, but E. Vredenburg correlated them with the Lower Nari (Stampian). The Padaung Clays overlie the Shwezetaw Sandstones, and are succeeded by rocks corresponding to the Singu Stage. They correspond to some of the upper horizons of the Sitsayan Shales of the Prome and Thayetmyo districts, and the term Sitsayan when used with palaeontological significance is equivalent to Padaung, although the Sitsayan Shales as a whole embrace the Shwezetaw Stage below and possibly some part of the Singu Stage above.

Similar shales near Ngahlaingdwin, Minbu district, were named locally by C. Porro the Kinmungyon shales, after the village of the same name. Cotter regarded them as equivalent to the Padaung Clays.

**Fauna.**—Some characteristic fossils occur in this stage both in the clays and the limestone. Those from the clays are *Cancellaria martiniana*, *Conus protofurvus*, *Turritella angulata*, *Genotia irrawadica*, *Solarium* sp., *Cyther* sp. The limestone contains the following :—*Lepidocyclina theobaldi* (=*Orbitolites mantelli* var. *theobaldi*), *Heterostegina* sp., *Pecten* sp., *Schizaster* sp. and *Lucina globulosa*.

**Singu Stage.**—The main fossiliferous horizon of the Singu oilfield is called the Singu Stage by E. Vredenburg, who has adduced evidence to show that the exposed Pegu rocks in the oilfields of Yenangyaung and Singu, and the higher beds in the oilfields of Minbu and Yenangyat are representatives of this stage.

According to Murray Stuart there is no representative of this stage in the Henzada district. In the Prome district it is represented by massive sandstones and shales to which Theobald applied the term " Prome beds " on account of the occurrence of their best sections in the river bank opposite Prome. The Prome beds rest conformably on the Sitsayan Shales, and

according to Theobald their thickness in the section opposite Prome is 1,995 feet, though this is not the total thickness of the Prome beds, as the Irrawaddy river intervenes between the exposures on the two sides of the river. The lower part has been called Prome beds (A) and consists of sandstones, hard, massive and flaggy or argillaceous, and shales, blue or yellow. The upper portion which has been called Prome beds (B) is the equivalent of the Singu Stage, and is very similar in lithological characters to the lower beds. In Upper Burma this stage is represented by shallow water marine deposits in the Minbu district and by deltaic and shore deposits in the Pakokku district.

**Age and Correlation.**—Vredenburg correlated this horizon with the Upper Nari as Chattian in age. An analysis of the Singu fossils shows that although they occur in separated beds, they form essentially one palaeontological unit, which is mainly Oligocene, though with some Miocene types. The general facies is older than the Kama fauna, and although the lowest fossiliferous bed may be in the upper limits of the Stampian, there is a general correspondence with the Chattian stage.

**Migyaungye Stage.**—Dr. L. Dudley Stamp has entered a plea for the recognition in the Pegu sequences of a Migyaungye Stage situated between the Singu and the Kama Stages as described above. The fossils include forms characteristic of both the Singu and Kama Stages.

The stage is named from the village of Migyaungye, on the banks of the Irrawaddy, near where there are excellent fossiliferous exposures. In that area the stage consists of alternating beds of sandy shales and shaly sandstones. The "standard fauna" of the Singu Stage is well defined and the numerous fossils have been described mainly from the Singu inliers. The "standard fauna" of the Kama Stage is equally well defined, but the fossils were obtained mainly from Lower Burma. In other words the "stages" of Vredenburg were not based on a study of successive faunas in one area. When Stamp examined the faunal succession through several thousand feet of strata in the area between Minbu and Thayetmyo it was not surprising to find that an intermediate Migyaungye Stage was to be distinguished between typical Singu beds and typical Kama beds.

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The stage is named from the village of Migyaungye, on the banks of the Irrawaddy, near where there are excellent fossiliferous exposures. In that area the stage consists of alternating beds of sandy shales and shaly sandstones. The " standard fauna " of the Singu Stage is well defined and the numerous fossils have been described mainly from the Singu inliers. The " standard fauna " of the Kama Stage is equally well defined, but the fossils were obtained mainly from Lower Burma. In other words the " stages " of Vredenburg were not based on a study of successive faunas in one area. When Stamp examined the faunal succession through several thousand feet of strata in the area between Minbu and Thayetmyo it was not surprising to find that an intermediate Migyaungye Stage was to be distinguished between typical Singu beds and typical Kama beds.

**Kama Stage.**—This is one of the most important stages of the Pegu Series. It is well represented in Lower and Upper Burma and has yielded numerous fossils. In Lower Burma the stage is represented by a series of shales with sandy beds and occasional sandstones and has been termed the "Kama Clays" by Theobald from the exposure 18 miles above Prome on the Irrawaddy at Kama. In the Henzada district it is wanting according to Murray Stuart. Lithologically they resemble the underlying Sitsayan Shales but differ from the latter in their fossiliferous nature. In the Thayetmyo district the deposit has been termed the Padaukpin Clay. In Upper Burma the stage is probably represented by the highest Pegu beds consisting of soft sandstones and clays which have yielded brackish water fossils, (*Batissa*). The presence of the Miocene mammal *Dorcatherium* in the higher part of the Pegu of Yenangyaung supports this correlation. In the Singu and Yenangyat areas it includes a thin band of shaly limestone of a pale bluish tint, purple shales and argillaceous limestone, weathering into soft clays with yellowish brown sandstones.

**Fauna.**—From the Padaukpin Clays the following fossils have been obtained :—*Lithodomus* sp., *Leda virgo*, *Corbula socialis*, *Turritella acuticarinata*, *Cerithium* sp., *Ficula* sp., *Balanus tintinnabulum*, *Hemipristis serra*, *Turritella angulata*, *Rimella javana*. *Pyrula promensis*, *Cassidaria echinophora* (var. *promensis*). *Ranella antiqua*. *Conus* (*Lithoconus*) *odengensis*, *Conus* (*Leptoconus*) *vimineus*, *Drillia protocincta*, *Surenta karenica*, *Terebra* (*Myurella*) *protomyurus*.

Besides these, mammalian fossils like *Dorcatherium* are also reported from this stage. This fauna is distinctly Miocene and according to Vredenburg it corresponds approximately to the Lower Gaj (Aquitanian) of Western India and is higher in the local succession than the fossiliferous Singu Stage. It is approximately equivalent to the Rambang Series of Java.

**Pyalo Stage.**—The Pyalo Stage is confined entirely to Lower Burma, and Vredenburg applied the name to a sandy group characterised by *Ostrea latimarginata* at Pyalo (19° 9′, 95° 14′) on the Irrawaddy river. It is equivalent to the Upper Gaj (Burdigalian) of Western India and lies above the Kama Stage. Dr. Stamp is of the opinion, however, that the Pyalo Stage is non-

existent. The bed, in which *Ostrea latimarginata* was found, is situated in the stream immediately to the north-west of Sitsaba village. Both above and below are other fossiliferous beds which, according to Dr. Stamp, appear to yield typical Kama faunas. At numerous neighbouring localities—Pyalo, Pyaye, Thanat and Kamagale, typical Kama faunas have been found to extend right up to the base of the Irrawaddy Series, leaving no room for the Pyalo Stage. Further, no other fossils distinctive of a Pyalo Stage have been found associated with the *Ostrea*.

**Akauktaung Stage.**—The Akauktaung Stage is named from the Akauktaung hills in the Henzada district. Murray Stuart gave this name to the beds which were regarded at the time as lying between an unconformity in Lower Burma above the Kama Clays and the "red beds" of Upper Burma. Previously the same author [1] had referred to them as "Marine beds of the Irrawaddy Series." They were regarded as Burdigalian (Lower Hinglaj) in age. Dr. Cotter has given reasons for grouping the Akauktaungs with the Pegu Series and has concluded that the unconformity was erroneously identified as such by Murray Stuart. The stage consists of coarse grits, occasionally conglomeratic, which vary in colour from yellow to red, and soft yellow sandstones which resemble the yellow sandstones of the overlying fresh-water Irrawaddy Series in a remarkable degree both in appearance and in the way they weather. However, they contain marine fossils. Blue shales are occasionally developed with bands of hard calcareous sandstones. The latter quickly weather to loose yellow sand, which resembles the weathered sand from the yellow sandstones mentioned above. In the field, the series is characterised by ridges of coarse grits, ferruginous in places, which are filled with fossils. It forms gentle undulating country characterised by loose, yellow sand, sometimes containing *kankar*.

In the Prome district, beds of the same age which overlie the Prome beds and the Kama Clays are composed of grits and sandstones.

**Fauna.**—*Ostrea gingensis*, *O. digitata*, *O. virleti* and *O. crassicostata*, *Arca burnesi*, *Cytherea erycina*, *Dione dubiosa*, *Turritella*

[1] *Rec. Geol. Surv. Ind.*, xxviii, 1910, pp. 266 and 274.

*simplex* and *acuticarinata*, *Conus literatus* and *C. avaensis*. From the beds of Upper Burma the fresh-water *Cyrena* (*Batissa*) *crawfordi* and *C. petrolei*, etc., have been obtained. Vredenburg correlates the Akauktaung Stage with his Talar Stage of the Mekran Series and with the Tji Lanang, or alternatively, Odeng beds of Java. The stage is regarded as Pontian or Vindobonian in age.

**Mogaung and Turritella Sands.**—The Mogaung and Turritella Sands were originally included by Theobald in his "Fossil wood group." Later researches have shown that they form the topmost member of the Pegus. They consist of a rather varied assemblage of beds of sand and shale containing sparingly both silicified wood and mammalian bones. In Upper Burma, this stage is represented purely by sand beds and conglomerates containing fresh-water fossils like *Cyrena* and *Batissa*. Farther north laterite and red beds are observed at the same horizon.

**The Pegu Series of the Oilfields (Upper Group).**—Farther north in Upper Burma, *e.g.* in the oilfields of Yenangyaung, Singu and Yenangyat, it has not been found possible to correlate accurately the Pegu strata with the stages described above in the Prome district. In Upper Burma the Pegu Series shows a rapid and capricious alternation of clays, sandstones and calcareous bands (*see* Plate XI, Fig. 1). There is every gradation between sandstone and shale, and it is very rarely that one free from the other exists. Sir Edwin Pascoe is of opinion that it must have been some such more or less porous mixture which gave rise to the erroneous idea that oil is contained in shale. It is, however, stated that porous sands and oil-sands when full of oil are of a dirty greenish colour, but when washed clean of oil are almost similar to water sands. Considerable lateral variation is observed and a sandy clay merges laterally into an argillaceous sandstone. Sometimes alternating layers of laminae, each from a fraction of an inch to a foot or more in thickness, of impure sand and clay, are observed. A tenacious clay of a light but rather intense blue colour is very characteristic, especially of the strata underground. It is brought to the surface by salses or mud volcanoes. According to Sir Edwin Pascoe this light blue clay is frequently found in a fresh stream-section at the crest of an anticline. Small crystals of pyrites

PLATE XI.

Fig. 1.—TYPICAL PEGU BEDS S[illegible] ALTERNATIONS

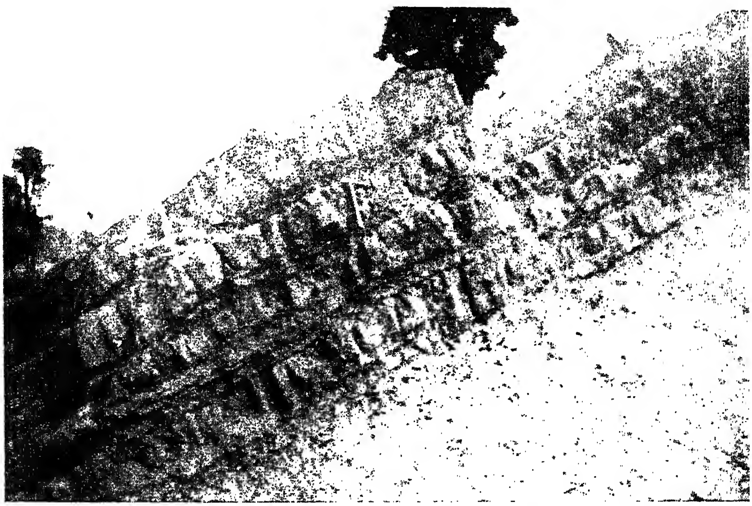

Fig. 2.—SHOWING VERY COARSE SEASONAL BANDING IN THE PEGUS, MINBU OILFIELD

are disseminated in these clays. There is sometimes a suggestion of lamination, when the clays approximate towards shale. " Cone-in-cone " structure is occasionally observed locally in calcareous mudstone, especially close to the Pegu-Irrawaddian boundary.

**Sandstones.**—The Pegu sandstones exhibit a very variable texture from that of a soft, friable sand-rock to a hard stone suitable for road-metal. They usually contain varying proportions of argillaceous material, they are not so coarse as the Irrawaddian sandstones and are firmer and less current bedded. Unweathered sandstones generally exhibit a greyish tint, but olive-brown or pepper-and-salt tints are also commonly seen.

**Calcareous Bands.**—Interbedded with the sandstones and shales are bands of hard calcareous and often fossiliferous strata which consist of sand, mud and oxide of iron with a calcareous matrix. These bands pass laterally into either sandstone or clay. Sometimes the proportion of arenaceous material is very small, yielding thereby a hard limestone. Conglomerates are not common in the Pegu Series. In the highest horizons of the Pegu, nevertheless, there is a tendency towards conglomerate conditions. Fossils are more commonly obtained from the calcareous sandstones, though they sometimes occur in the impure clays, where the best specimens are obtained. Old " shell-banks " are common, consisting of comminuted fragments more or less cemented together by calcareous matter derived from the shells themselves. Similar deposits were observed by Theobald forming at the present day all along the Arakan coast.

**Seasonal Rhythm.**—Dr. L. Dudley Stamp [1] has shown lately that the sediments of the Pegu Series range, broadly speaking, from pure sand-rock to homogenous clays. The intervening stages for the most part comprise well-bedded sediments consisting of alternating laminae of sand and clay (*see* Plate XI, Fig. 2). It is found that the laminae vary in thickness, sometimes the clay band is thicker, sometimes the sand. He has explained this lamination as a result of the varying carrying capacity of the river or rivers which poured sediment into the

[1] *Geol. Mag.*, vol. lxii, 1925, pp. 515-528.

Burmese gulf. Each double lamina would represent the sediment of a single year, the finer portion being deposited during the river's low water season and the coarser portion during the high water or flood season. Dr. Stamp has actually calculated the number of *laminae* in several sections of the Pegu Series and has concluded that it covers a period of $2\frac{1}{2}$ million years at least, which marks the duration of the whole of the Oligocene and half of the Miocene. He has further adduced that a comparatively fine-grained sand may have been piled up at the rate of a foot in twenty-five years, whilst numerous calculations as to the rate of deposition of alternating sands and clays give an average of a foot in sixty years. Even a homogeneous clay may be laid down as rapidly as a foot in 200 years or even less.

**Fossil wood and similar organic remains.**—Siliceous, calcareous, ferruginous and sometimes carbonised fossil wood is found in the Pegu Series, especially close to the Pegu-Irrawaddian boundary, but is never so common as in the overlying Irrawaddian Series. Sometimes a little lignite, carbonaceous leaf impressions and thin laminae of coaly matter are also found. According to Sir Edwin Pascoe, these occur more plentifully in localities where there are signs of shallower and fresher water conditions. The fossil resin or amber is also found in the series under description at Yenangyaung and Yenangyat oilfields.

**Fresh-water fossils.**—In some places fresh-water shells, *Cyrena* (*Batissa*) *khodaungensis*, *B. crawfurdi* or similar species, are found within 400 feet of the upper boundary of the Pegus. Dr. Cotter collected them from the Pegu Series of the Salin subdivision. According to Sir Edwin Pascoe, each patch of the fossils was formed in a fresh-water pool or back-water left by a river at the end of the Pegu period. Terrestrial vertebrate remains, though rare, do occur in places.

**Marine fauna.**—The marine fauna of the Pegu Series, especially as characteristic of its various stages, has been referred to already. The fauna, on the whole, is of a shallow water character, but conditions varied locally, such as would happen in a silting-up gulf. Sir Edwin Pascoe has concluded that there is often a very marked lateral variation in the composition of the fauna

and, furthermore, the variation in the fauna of equivalent horizons is very striking. A bed of fragmentary dendroid corals may pass into a bed of ordinary pelecypods and gastropods. The variation is as great vertically as it is laterally. Dr. Noetling found that in all his zones there were invariably present some genera which do not go beyond a depth of 25 metres of water, so that this must have been the average depth of the gulf between Prome and Yenangyat. Several writers have remarked upon the dwarfed and stunted nature of the Pegu fossils. Sir Edwin Pascoe asks whether the peculiarity is specific or individualistic. It is compatible with saline conditions obtaining for a greater part of the year when the pouring in of the fresh-water sediments by the rivers into the gulf was very greatly diminished.

**Correlation and Age.**—Although the Pegu deposits have been studied in considerable detail on account of the occurrence of petroleum in them, their correlation has been by no means an easy task. The classification followed here is still only provisional. This is due to the lateral change of facies; each stage is represented by gradually shallower conditions, when the Pegus are traced northwards, the change even amounting to the replacement of marine by estuarine and fresh-water beds. The geological ages of the different beds have been summarised by Vredenburg in the following words: "The Oligocene of Burma includes three divisions; a lower one, the Shwezetaw Sandstone, a middle one, corresponding with the Padaung Clay or with the Sitsayan Shale, and an upper division which may be distinguished as the Singu Stage. This series is well circumscribed in geological sequence by the underlying Upper Eocene age of the fauna of the underlying Yaw Stage, and by the satisfactory Aquitanian age of the overlying Kama Stage. No widespread unconformity has been detected either at the upper or lower limit of the series which, moreover, consists of a consistently continuous sequence and which therefore must embrace the whole of the Oligocene. Therefore, we cannot run risk of error if we assimilate the three stages of the Burmese Oligocene respectively with the three divisions recognised by western geologists, namely the Lattorfian, Stampian and Chattian, for the lower division, the Shwezetaw Sandstone must

necessarily coincide in part at least with the Lattorfian ; while it is most improbable that the Padaung or Sitsayan Stage, however much it might happen to be situated astride of two divisions, would entirely miss the middle division of the western geologists, the Stampian." In brief, it may be mentioned that the age of the Pegu System ranges from Oligocene to Mid-Miocene.

A table showing the correlation of the Pegus as observed in different parts of Burma is appended below.

Recently G. W. Lepper,[1] as a result of his own work and that of his colleagues in the Burma Oil Company, has shown the Pegu Series to consist of some 20,000 feet of strata, approximately equally divided between the Pliocene and the Miocene. At the base, the very sudden change in the character of the fauna, notably the disappearance of the abundant Nummulites of the underlying Yaw Stage, indicates that there may be a palaeontological break between the Eocene and the Oligocene ; while a definite break separates the latter from the overlying Miocene (Pyawbwe Clays).

The subdivisions of the Pegu Series recognised by the geologists of the Burma Oil Company are as follows :

| | |
|---|---|
| Miocene. | Obogon Alternations, consisting of rapidly alternating thin beds of sand and clay. Marine fossils have been found indicating an Upper Miocene (Helvetian-Tortolian) age ...... up to 3,000 ft. |
| | Kyaukkok Sandstones, include the " Prome Sandstones " of Theobald, and the highest Pegu sandstones of the central oilfields in part. A rich fauna, marked by a preponderance of lamellibranchs indicates a Middle Miocene (Burdigalian) age ...... up to 5,000 ft. |
| | Pyawbwe Clays, consisting chiefly of concretionary grey to blue sandy clays, with gypsum and several thin sandstones. Fossils are abundant and prove the Lower Miocene (Aquitanian) age of the Beds ...... up to 3,000 ft. |

[1] "An Outline of the Geology of the Oil-bearing regions of the Chindwin-Irrawaddy Valley of Burma, and of Assam-Arakan." *Proc. World Petroleum Congress*, London, 1933.

## Table Showing the Correlation of the Pegus as seen in the Different Parts of Burma.

| ...... | Minbu (west) | Thayetmyo | Prome | Henzada | Stage name | N.W. India | Java | N.W. Europe |
|---|---|---|---|---|---|---|---|---|
| | Deltaic and shore deposits | Mogaung and Turritella sands | Marine Irrawaddy | Akauktaung beds | Akauktaung | Talar | | |
| Upper Pegus | | | | | Pyalo (?) | Upper Gaj | Njalingdun series | Burdigalian |
| | Do. | Kama clay ? Padaukbin clay | Kama clay stage | (wanting) | Kama [Migyaungye] | Lower Gaj | Rembang series | Aquitanian |
| | Shallow marine deposits | Letpanzeik beds | Upper Prome stage | Do. | Singu | Upper Nari | | Chattian |
| Middle Pegus | Do. | Do. | Lower Prome stage | Do. | | | | |
| | Padaung clay | *Lepidocyclina* beds | Sitsayan shale | *Lepidocyclina* Limestone and associated Sitsayan shale | Sitsayan | Lower Nari | | Stampian |
| Lower Pegus | Shwezetaw sandstones | ? Coal measures of Lime Hill | ? Lower part of Sitsayan shale (doubtful, no fossils) | ? Lower part of Sitsayan shale | Shwezetaw | | | Lattorfian |

*Palaeontological break.*

| | |
|---|---|
| Oligocene. | Okhmintaung Sandstones, very variable in thickness, consist of sandstones, sometimes conglomeratic, with thin grey clays. The fauna is believed to be of Chattian age ... up to 3000 ft.<br>Padaung Clays, contain numerous fossiliferous bands, including a foraminiferal limestone, and the fauna is typical Middle Oligocene ...... up to 2,500 ft.<br>Shwezetaw Sandstones is essentially an arenaceous group, with a more argillaceous development locally in the south. The fauna is not rich, but indicates a Lower Oligocene age. 2,000 to 4,000 ft. |

**Physiography at the end of the Pegu period.**—It is needless to repeat here that there was much lateral variation in the shoreline during the whole period of the deposition of the Pegus, and that the Burmese gulf was growing shallower as time progressed. One thing at least is clear and that is, that while the northern part of Burma had definitely assumed a continental facies, probably even as early as the Miocene period as evidenced by the deltaic and shore deposits of the stages above the Singu, in Lower Burma marine conditions still prevailed as revealed by the marine fossils of the Akauktaung Stage. Another factor worth noting here is that even in Lower Burma, the gulf must have become comparatively shallow as proved by the vast amount of blue clay (characteristic of shallow water deposits) constituting this region.

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# CHAPTER XXIV

## THE IRRAWADDY SERIES

### PONTIAN TO PLIOCENE

THE fluviatile sands with fragmentary remains of terrestrial and aquatic vertebrates, overlying the Pegu Series, sometimes with a marked, but more frequently with a slight unconformity, were first termed " Fossil Wood Group " by Theobald on account of the enormous quantities of fossil wood so plentifully dispersed through them. But later this term was discarded in favour of the Irrawaddy Series or the " Irrawaddian." It is by the abundant occurrence of silicified fossil wood, by the association of ferruginous, calcareous and siliceous concretions, and quartz pebbles, and by the rather incoherent nature of the coarse, generally false bedded sands that the Irrawaddian rocks are distinguished from the other Tertiary rock groups.

**Distribution.**—The sand-rock, sandstones and clays of this series have a very extensive distribution (see Plate XXIV). On the northern side they have been noted to occur in the Katha and the Lower and Upper Chindwin districts. In the Myitkyina district the writer has described their equivalents as the Namting Series.[1] Excellent sections of these beds are seen in the cliffs of the Irrawaddy between Magwe and Sale. On the southern side, there are indications to show that they stretched as far as Rangoon. If we take note of the amount of denudation that this formation has undergone and also consider that the Irrawaddian is covered in many places by post-Tertiary deposits, it is probable, according to Theobald, that the Irrawaddian rocks may have extended even up to the southernmost point of Burma in Cape Negrais. On the west, these deposits lie

[1] *Rec. Geol. Surv. Ind.*, vol. lxvi, 1932.

roughly in a line parallel to long. 94° 30′ in Upper Burma; in Lower Burma their exact western boundary is not known. Theobald, however, believed that they extended in a line approximately coincident with the eastern flank of the Arakan Yoma. The existence of beds of Irrawaddian type east of the Pegu Yoma has been recorded, though in isolated exposures.

Taking all these facts into consideration it can be said with a fair degree of accuracy that the Irrawaddian rocks occur almost over the whole basin of the Irrawaddy river.

**Thickness.**—The thickness of the Irrawaddy formation was variously computed in the early days. Noetling estimated its thickness at 20,000 feet; but subsequent work has shown that this is nowhere near the correct figure. A good section exposed in the Yenangyaung area shows a thickness of 4,000 feet. Near Yedwet it is estimated that it is nearly 5,000 feet, while Cotter [1] gives the thickness as probably about 6,000 feet, and Lepper uses the figure 5,000—10,000 feet.

**Relationships with the older rocks**—The disposition of these beds on the underlying Pegu rocks is not quite uniform throughout. In the Yenangyaung area there is a slight unconformity at the junction of the two groups. In Magwe, Myingyan and Pakokku districts an unconformity, though local, is indicated. In the lower Chindwin region at Medin, Myaing and Shinmadaung the basal beds of the Irrawaddian rest with marked unconformity upon Peguan or Eocene rocks. In other areas the Pegu beds are seen to pass insensibly into the overlying group. It appears that the unconformities observed between the Peguan and the Irrawaddian are of a local character as generally there is a remarkable parallelism of dip between the two series. Sir Edwin Pascoe [2] remarks: "It is not always possible to draw a well-defined boundary line between the Pegu and Irrawaddian, a condition of affairs we might well expect since, during the slow uneven elevation, brought about by crumpling lateral movement, of marine or deltaic sedimentary strata above the surface of the gulf at the end of the Pegu times, there must have been local oscillations between salt water and fresh water conditions."

[1] *Journ. Proc. Asiatic Soc. Beng.*, N.S., vol. xiv, 1918, pp. 415.

[2] *Mem. Geol. Surv. Ind.*, vol. xl, 1912.

A " Red bed " which occurs commonly at the base is sometimes taken as being the lowest member of this group ; but it is unfortunately not present in all Pegu inliers, nor always continuous round the same inlier, and sometimes more than one " Red bed " is seen. A " Red bed " is probably the relic of the old lateritic soil upon which the overlying fresh-water deposits were laid. This " Red bed " in its commonest form consists of a brick-red clayey sand, soft, friable and easily removed by agents of denudation. These beds denote the first striking change in the deposits. Terrestrial vertebrate remains are very rare below them, but are occasionally found in the conglomeratic variety of the Red bed itself and are plentiful in the strata immediately above. Similar ferruginous or lateritic bands have been recorded as occurring between the Ranikot and Kirthar and between the Kirthar and Manchar in Western Sind. Vredenburg considers them to be undoubted proof of continental conditions.

**Lithology.**—The lower Irrawaddian beds exhibit a wide range so far as their lithology is concerned. " Red beds " associated with a number of thin, inconsistent ferruginous conglomerate bands or with highly clayey beds have been noted. Clay, however, occurs most commonly in pockets. Where the clay beds occur they show curious tints and frequently small quartz pebbles and gypsum are also seen. In certain areas loose pebble beds consisting of quartz pebbles, either pure or coated with iron oxide, constitute the lower portion of this system. Besides this, we find pebbles of sandstone, ochreous mudstone, schist veined with quartz and, at Yenangyaung and elsewhere, of a silicified rhyolite as from Kyaukpadaung near Mount Popa, Myingyan district. According to Sir Edwin Pascoe, in the majority of cases, the size of the pebbles in the same locality increases as they rise in the series ; every gradation is found between fine sand, coarse sand, and pebbles ranging up to a diameter of 18 inches. It is from these ferruginous conglomerates that the pebbles of the Plateau Gravel were derived. Their ultimate origin is the Negrais and Axial Series of the Arakan Yoma. The middle or rather the major portion of this series is made up of loose, friable, clean, yellow-coloured, current-bedded and iron-stained sand-rock, sandstones of various

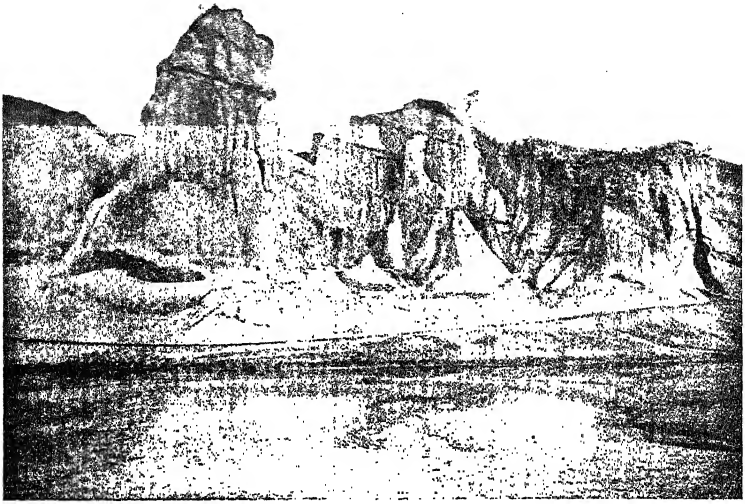

FIG. 1.—"COMPOUND BUTTRESS" WEATHERING OF IRRAWADDIAN SAND-ROCK, YENANGYAUNG.

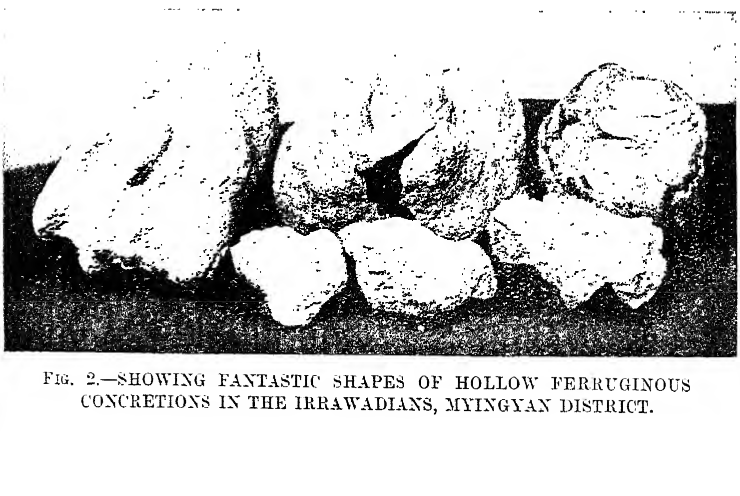

FIG. 2.—SHOWING FANTASTIC SHAPES OF HOLLOW FERRUGINOUS CONCRETIONS IN THE IRRAWADIANS, MYINGYAN DISTRICT.

colours with occasionally interbedded clays and finely laminated, greenish, friable, argillaceous sandstones. Subangular waterborne quartz particles constitute the greater portion of the sand bed ; felspar and mica particles also occur frequently. Sometimes the sand-rock encloses masses of hard, rounded, calcareous sandstone. As described in detail by the author [1] these rocks enclose all sorts of fantastic, ferruginous concretions which were smelted for iron under the Burmese rule (see Plate XII, Fig. 2 and Plate XIII). These concretions are often hollow with a kernel of clay and the material is largely hæmatite with limonite in places. Occasionally they are embedded in thick bands of ferruginous conglomerate which consists mostly of quartz pebbles cemented by a ferruginous matrix. Besides these, calcareous concretions having root-like and spheroidal forms are also commonly found. Surface layers are often coloured red, forming the " Red earth " by the leaching of iron salts derived from the ferruginous concretions during the rainy season. The salts are drawn to the surface by the force of capillarity and are deposited subsequently during the period of drought. Sometimes manganese, probably in the form of psilomelane, takes the place of the iron ore. The presence of silicified wood and curiously shaped calcareous and siliceous concretions in the Irrawaddian affords strong evidence of the activity of various types of mineralising solutions through the sands. The peculiar weathering of the sand-rock into " bad lands," earth pillars and compound buttresses (Plate XII, Fig. 1) has already been referred to above.

Flat slabs of calcareous sandstone are fairly common in the sand-rock but do not attain any great vertical or horizontal dimensions. Layers of sand and clay alternate, especially towards the base of the series. Balls of clay, up to one or two feet in diameter are common in the sand-rock.

**Fauna.**—To the palaeontologist the Irrawaddian rocks are highly interesting as they have yielded a number of vertebrate fossils, mostly mammalian. Remains of hippopotamus, rhinoceros, elephant, pig, tapir, oxen, deer, antelopes, the garial and alligator with the fresh-water tortoises *Trionyx* and *Emys*, have been obtained from them. The occurrence of the bones

[1] *Journ. Proc. A.S.B.*, N.S., vol. xxi, 1927.

throughout the deposit is irregular, local and capricious. Some of the fossils that have been obtained are :

*Carcharodon*, *Collossochelys atlas* (the gigantic land tortoise), *Gharialis gangeticus*, *Gharialis leptodus*, *Mastodon latidens*, *Mastodon elephantoides*, *Stegodon clifti*, *Hippopotamus sivalensis*, *Hippopotamus irravaticus*, *Merycopotamus dissimilis*, *Vishnutherium irravadicum*, *Hydaspitherium birmanicum*, *Hipparion punjabiense*, *Aceratherium lydekkeri*, *Rhinoceros sivalensis*, *Tetraconodon minor*, *Taurotragus latidens*, *Cervus* sp., etc., etc.

In Lower Burma and in the Arakan coast, in addition to the presence of reptilian and mammalian remains numerous sharks' teeth have been obtained from the lower Irrawaddian beds. Most of the species found in Burma are common to the Siwaliks of the Sub-Himalayas and the Salt Range: *e.g. Colossochelys atlas*, *Hippopotamus sivalensis*, *H. viravaticus*, *Merycopotamus dissimilis*, *Rhinoceros sivalensis* and *Emyda palaeindica*. The living *Gharialis gangeticus* of the Ganges and Jumna and *Gh. leptodus* are found in Burma and the Sub-Himalaya. *Vishnutherium irravadicum* besides being found in Burma, also occurs in the Salt Range. Some of these species have a very wide range and have been found outside the Indian Empire, *e.g. Stegodon clifti* is found in India, China and Japan. In China a number of forms common to the Siwaliks of India and the Irrawaddy Series of Burma are found.[1] There is little doubt, therefore, that the Siwalik conditions of deposition extended eastwards from India into Burma, China, Japan, Borneo, Java, etc. Northwards Siwalik remains have been found in the Pleistocene of Tibet. Westwards they are not known to occur in Afghanistan, Baluchistan and Persia.

**Nature of Fauna.**—According to Dr. Noetling, out of 26 species found in the Irrawaddian Series, six are entirely of aquatic habit and two are semi-aquatic. Seven to nine lived chiefly in marshy swamps, while the remaining eight are identical with Indian Siwalik forms. Out of the 26 species, 11 at least are identical with the India Siwalik forms.

[1] *Mem. Geol. Surv. Ind.*, vol. xl, 1912, p. 38.

FIG. 1.—HOLLOW, FERRUGINOUS CONCRETIONS FROM THE IRRAWADDIAN SANDS, MYINGYAN DISTRICT.

FIG. 2.—SHOWING CONCENTRIC BANDED STRUCTURE IN A LIMONITIC CONCRETION ("TOROLITE") FROM IRRAWADIANS NEAR MOUNT POPA.

**Fossil wood and its origin.**—With the exception perhaps of precious stones like rubies the fossil wood of Burma has attracted the attention of travellers more than any other mineral substance. It was noticed as early as the end of the eighteenth century, or early in the nineteenth, by travellers like Symes, Crawford, Yule and Oldham. The Burmese always refer the fossil wood to *Ingyin* (*Pentacme suavis*), which grows so commonly in those parts. Both monocotyledonous and dicotyledonous fossil wood (*see* Plate XIV) have been recorded from the Irrawaddy Series and the former includes palms from close to the Pegu-Irrawaddian boundary. As regards the dicotyledonous wood, which forms the bulk of the material, Miss Ruth Holden has described *Dipterocarpoxylon burmense*. The monocotyledonous wood represents the remains of palms which show very clearly the cordiform vascular bundles and their obliquity to the stem axis when about to enter a leaf. Years ago certain quaint theories were advanced to explain the origin of fossil wood and a detailed account of them is given in the writer's paper on "The Origin and Mineral Constitution of the late Tertiary Fossil Wood of Burma" mentioned in the list of references at the end of this chapter. Theobald attributed the silification of the wood to the agency of springs consequent upon volcanic activity. Such a theory has to be rejected not only because of the absence of siliceous sinter and cherty beds but also of the discrepancy in age between the Irrawaddy Series and the main volcanic rocks of Burma, some of which are decidedly younger than the former. Xenoliths of fossil wood are even found associated with the andesitic lava of Mount Popa.

Murray Stuart presumed that the wood was fossilised on the Arakan Yoma by siliceous springs and that it was merely a case of its transportation and preservation in the Irrawaddy rocks. Apart from the difficulties presented, when one supposes silicified logs 50 feet long to have been transported more than a hundred miles, we find that the fossil wood is mainly confined to siliceous beds and is conspicuously absent from the silty under-clays. Again, the siliceous injections in the Negrais rocks are too compact and fine-grained to yield the quartzose sands of the Irrawaddy Series. Above all, the fossilisation of wood of

Pliocene age cannot be attributed to the siliceous spring phase which characterised the Cretaceous period only and did not survive later. The source of the fossil wood is not extraneous but within the Irrawaddian arenaceous strata themselves, and the fossilisation of wood was contemporaneous with the deposition of the Irrawaddy Series.

The constitution of the fossil wood is siliceous, calcareous, ferruginous and carbonaceous. Chalcedony and microcrystalline silica generally and opal occasionally, form the bulk of the specimens, while calcite and siderite have also participated in the formation of some others. In exceptional cases quartz has been deposited in the broad bundles of the vascular tissues while the parenchymatous tissue has been replaced by carbonates of iron and calcium.

The origin of fossil wood is due to colloidal material associated with waters laying down the deposits in which it is preserved. The lithology of the Irrawaddy Series supports such an origin. Both mechanical and chemical weathering must have helped in the formation of the colloids, some of which seem to have been changed into crystalloidal forms afterwards.

The author has proved the colloidal origin of the wood by experimental tests which included staining, specific gravity determinations, water of constitution and microscopic examination, etc. The structures of some of the concretions associated with the fossil wood show rhythmic banding or the so-called *liesegang* rings, and it is probable that the solutions which originated these concretions were also instrumental in the replacement of the wood.

Fresh-water desert (playa) conditions are favourable to the formation of fossil wood especially when a great deal of alkali is present to decompose the silicates and liberate colloidal silica to be deposited in the woody tissues.

The presence of monocotyledonous fossil wood, especially along the Pegu-Irrawaddian boundary, seems to point to the climate of the Irrawaddian being a dry one in Central Burma, and it may be that the uprise of the Arakan Yoma at the close of the Peguan epoch interrupted the rain-bearing monsoon winds, and established the dry, rain-shadow area which persists to the present day.

PLATE XIV.

SHOWING THE CROSS-SECTION OF A TRUNK OF FOSSIL WOOD FROM THE IRRAWADDIANS, NEAR PROME.

**Mode of deposition.**—From the lithology as well as the palaeontology, it is concluded that the Irrawaddy Series is in the main a continental deposit. From the irregular distribution of the fossil wood we have also to infer that they were formed mostly as drift deposits. Stumps of trees have been obtained with the roots upside down. In some places only portions of branches are met with. In brief, there is evidence to show that they were accumulated in shallow basins. From the association of sharks' teeth with these it was held at one time that they have been accumulated probably in an arm of the sea. But this view has been abandoned as it is now known that some species of sharks do enter the mouths of some of the important rivers, many miles away from the seashore. They may have equally been derived from the Pegu Series by erosion.

Lydekkar remarked that "the whole of the Siwalik Mammalia belonged to genera fitted for life in the plains or in low jungle-clad hills, not barren and lofty mountains." The conditions under which the Irrawaddy Series was deposited were a modification of those under which the Siwaliks of the Sub-Himalayas were accumulated. According to Sir Edwin Pascoe they represent the accumulation along the base of hill slopes, of vast fans of river detritus, through which the main river meandered.

**Age.**—The Irrawaddy Series from vertebrate fossil evidence can be correlated with the Siwaliks of India and Manchar Series of Sind. The vertebrate fossils from the Irrawaddians at Yenangyaung come from two distinct horizons :

(*a*) Lowest beds containing *Hipparion punjabiense*, *H. lydekkeri*, crocodilian and chelonian remains. According to Dr. L. Dudley Stamp *Mastodon* and *Hippopotamus* seem to be rare or absent at this lower horizon.

(*b*) A conglomerate band some 4,500 feet higher in the series, and exposed along the banks of the Irrawaddy between Yenangyaung and Nyaunghla yielding numerous specimens of *Mastodon latidens*, *Stegodon clifti* and *Hippopotamus irravaticus*.

The lowest beds of the series may be correlated with the Dhok Pathan (Pikermi) horizon of North-Western India. This indicates an Upper Pontian age. Dr. Stamp adds that since

*Mastodon* and *Hippopotamus* both seem to be absent, the beds may possibly be homotaxial with the Nagri horizon (Lower Pontian). Moreover, the presence of *Aceratherium* indicates a pre-Pliocene age. The higher horizon indicates the Tatrot horizon (Lower Pliocene) of North-Western India. According to Dr. Stamp there are also Upper Pliocene deposits in the Irrawaddy Series as he has obtained the remains of *Bos elaphus* and *Bos* sp. about lat. 22° 3′. The fossil *Unionidae* from the basal Irrawaddy beds in the Thayetmyo district described by E. Vredenburg and B. Prashad are closely related to living Burmese species, while the single Melaniid found (*Acrostoma variabile*) is still living. It will therefore be seen that the Irrawaddy Series ranges in age from Pontian to the end of the Pliocene, corresponding to the Middle and Upper Siwaliks of India and the Dihing Series of Assam.

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# CHAPTER XXV

## TERTIARY DEPOSITS OF SHAN PLATEAU AND TENASSERIM

LATE Tertiary deposits occur in the present river valleys of the Northern and Southern Shan States, the Amherst, Tavoy and Mergui districts. In the Shan Plateau they are coal-bearing, in the eastern part of the Amherst district they contain oil-shale, while in the Mergui district they carry both coal and oil-shale. In almost every case they form synclinal basins, and by crustal movements and denudation sometimes an originally continuous outcrop has been reduced to small, disjointed patches. On account of the association of the two different economic products, the coal-bearing and oil-shale Tertiary deposits are described below separately.

### Northern Shan States.

After its upheaval at the close of the Mesozoic era the Shan Plateau has been an area of denudation and degradation, subject to the action of the agents of weathering. During the whole of the Eocene, Oligocene and Miocene periods, when active deposition was going on in the valley of the Irrawaddy, the main physical features of the plateau were being carved out. After the formation of the hills and valleys a few deposits, of fresh-water or lacustrine origin, were laid down in the basins of rivers and lakes.

**Lithology.**—The Tertiary rocks of the Shan Plateau consist of silts and soft sand-rock with pebble- and boulder-beds and seams of brown lignitic coal. The sand-rocks are so slightly consolidated that they break down into a soft mud when immersed in water. They are found as detached outcrops

occupying the present river valleys, and it is significant that they are confined to the portion of the plateau surrounding the high ground culminating in the lofty peak of Loi Ling, the highest point in the Federated Shan States.

**Distribution.**—The Tertiary deposits of the Northern Shan States are particularly well developed in the following six areas and have been fully explored on account of the association of lignitic coal with them.

1. A small patch of these rocks surrounds the village of Mongyaw (23° 2′, 98° 9′) situated in the upper part of the Namyau valley. La Touche says that he searched for coal in them in 1900, but without success. This area is separated from the Lashio coalfield by a broad band of the Namyau sandstones.

2. The basin of the Lashio coalfield lies in the upper part of the Namyau valley, extending from Mongyaung westwards to Hsunkwé, a few miles north of Lashio. It is about 15 miles in length with an average breadth of 4 miles. The Tertiary deposits were laid uniformly on the Plateau Limestone, and also on the Namyau sandstones, and the silts cross an important fault which cuts the river close to the ford north of Lashio and is marked by a line of hot springs. The beds are composed of sandy clays and soft sandstones with very subordinate pebble bands and an occasional layer of harder ferruginous sandstone. Outcrops are only to be seen along the course of the river and the coal seams are confined to the lower portion of the formation.

3. The coalfield of Nammá forms perhaps the most important Tertiary basin as it contains the most promising coal seams. Its principal axis follows a north-east—south-west direction. The coalfield is 15 miles in length, with an average breadth of 3¼ miles. The lithology of the deposits here is different from the normal; sandy silts are subordinate, while clayey shales of a whitish to light-brown colour predominate, and amongst these coal-seams are intercalated with soft sandstones and conglomerates. In the neighbourhood of Man-Sé the clays are pure white, resembling kaolin. Conglomerate, formed of pebbles and boulders of quartz and crystalline rocks, ranks next in importance. The coal seams, as in the Lashio coalfield, are

confined to the lower horizons of the deposit. There is a great variation in dip, which is believed to be due to underground subsidence of the limestone floor, but occasionally contortion of the rocks due to folding can be observed.

4. About 3 miles south of the Nammá coalfield there is another small outlier of these deposits, which has a length of 4 miles and a breadth of about half a mile. No outcrops of coal are known in this area.

5. The fifth basin of Tertiary deposits is constituted by the Mán-sang field, lying in the South Hsenwi State and about 16 miles to the south of the Nammá coalfield. It extends for about 13 square miles, but its southern and south-eastern boundaries are very ill-defined. The coal-bearing rocks consist of yellow, white or grey shales, which are occasionally sandy, and the dip is variable.

It is interesting to note that the volcano of Loi Han Hun, described below, has burst through these deposits near the edge of the basin.

6. The last of the Tertiary basins includes the Mán-se-lé field. It is irregularly oval in shape, the northern or the longer axis being $4\frac{1}{2}$ miles in length, while the shorter axis is about a mile less. It covers an area of about 16 square miles. The boundary of the field on all sides is of Palaeozoic limestone, and the Tertiary rocks consist of yellow-brown shales with occasionally a sandy character, and coal-seams. On the southern boundary of the field near Mankün, occurs an interesting outcrop of white kaolin-like clay, similar to that at Mán-Sé in the Nammá field. The clay seems to have filled a fissure in the limestone floor of the basin. It now resembles a dyke with vertical walls on either side, and the limestone which enclosed it has been removed in solution.

**Fossils.**—The fossils which occur in these beds include leaves of plants and shells of gastropods of fresh-water types; they are very friable. In the Lashio coalfield Noetling found specimens belonging to the genera *Planorbis* and *Limnaea*. From the Nammá coalfield specimens belonging to the families *Hydrobidae* and *Viviparidae* have been recorded.[1]

**Age.**—The evidence available for determining the age of these

[1] *Rec. Geol. Surv. Ind.* vol. l, 1919, pp. 222-224.

deposits is very meagre. However, it indicates an extremely late Tertiary or perhaps even Pleistocene age. These deposits were laid down before the cessation of orogenic activity in this region, and the basins, in which they were accumulated, were most probably formed by the "warping" of the surface of the plateau, the physical features of which had been already carved out into their present outlines. La Touche was inclined to correlate the deposits with the Pleistocene gravels of the Narbada, Tapti and Godavari rivers in the Peninsula of India, which according to Vredenburg[1] were accumulated in basins due to "warping" of the surface in Pleistocene times.

**Extension into Yunnan.**—Similar deposits, to which he gave the name of Nam Tien Series, occur, according to Coggin Brown, in Yunnan. They are found in the valleys and contain lignite intercalated with them. A species of *Bythinia*, identical with one still living in the Erh-Lai lake at Ta-li-fu, occurs in them.

### Southern Shan States.

C. S. Middlemiss was the first geologist to investigate the elongated outcrops of late Tertiary lacustrine deposits in the Southern Shan States. They consist of coarse, loose conglomerates and pebble beds with bands of light-coloured sandrock, bluish-grey clays and loams. The pebbles are generally composed of hard quartzite, but sometimes of limestone. They are horizontal or show only insignificant dips. The deposits spread out and thin away locally along the stretches of the level plateau. The best outcrops exist in the Thamakan valley. In the latitude of Thamakan village their width is 7 miles, but they gradually diminish, ultimately ending with a width of $1\frac{1}{2}$ miles south of Poila.

These Tertiary beds are often crumpled and faulted locally by movements caused through the solution of the underlying limestone floor. According to Dr. Coggin Brown, the crushed and distorted, soft, yellow and yellowish-red sandstones, which occur in cup-shaped depressions in the limestone just to the

[1] *Rec. Geol. Surv. Ind.* vol. xxxiii, 1906, pp. 33-45.

south of Kyong, most probably represent these Tertiary deposits.

**Mode of Origin.**—Dr. Coggin Brown is of the opinion that there is little doubt that the clays and sands are true lacustrine deposits, the pebble beds representing torrential deposits, carried down into the lakes during times of flood. These deposits are precisely similar to the Tertiary deposits of the Northern Shan States and Yunnan described above. There is a very close connection between the three valleys of Thamakan, He-ho and Yawnghwe: the lowest point of the former is about 4,130 feet above the sea, the levels of the other two are 3,785 and 2,915 feet respectively. There is thus a progressive decrease of levels of 345 and 870 feet from the first to the third. Coggin Brown [1] believes that the lake deposits of the Yawnghwe valley have gone on continuously forming from Plio-Pleistocene times to the present day, that in the He-ho valley they ceased in comparatively recent times, and that in the Thamakan valley deposition ceased before this. That there has been a recent uplift is proved by the elevation of certain clays and pebble beds in the Yawnghwe valley.

### Tavoy District.

Tertiary deposits in the Tavoy district occur along two belts, the one coinciding with the present valleys of the Ban and Kamaungthwe and the other to a less extent with the Great Tenasserim. These belts have been areas of depression along parallel axes, separated by a more elevated barrier about 20 miles wide.

**Outcrops.**—The Tertiary rocks occur as a number of disconnected patches, and according to Drs. Coggin Brown and A. M. Heron they were originally accumulated in broad river valleys or possibly in a lake.

**Lithology.**—The Tertiary rocks are composed mainly of conglomerates and shales with sandstones, which are coarse, false-bedded and contain pebbly layers. There is a gradation upwards from coarse deposits at the base to fine sediments at the top. Owing to the synclinal arrangement, therefore,

[1] *Rec. Geol. Surv. Ind.* vol. lxv, 1932, p. 406.

conglomerates crop out round the edges of the basins and the shales occur in the centres. Thin impure limestones and lenticular bands of lignite about six inches thick occur near Kyaukton. The pebbles in the conglomerate, which are often set in a ferruginous matrix, were derived from vein quartz, granite, quartzites and argillites of the Mergui Series.

**Age.**—Excluding fragments of silicified and carbonised wood no organic remains have yet been found in these deposits. In the absence of fossil evidence it is impossible to assign them any definite age, but, from their general facies and from the presence of silicified wood, Dr. Coggin Brown and Dr. A. M. Heron were of the opinion that they may be tentatively correlated with the Irrawaddy Series of Central Burma.

**Structure.**—The Tertiaries have been thrown into basins and they show irregular disturbance. At the margin dips of 20°–40° predominate, but they flatten out to low angles, almost approaching horizontality towards the centre. Minor faults are not uncommon.

## Mergui District.

The Tertiary deposits of the Tavoy district extend irregularly into the Mergui district over a total distance of 220 miles. Though they occur now as disconnected outcrops, perhaps they were continuous originally. The old river valleys coincide with their present courses, and the chief outcrops according to their geographical distribution can be grouped as follows :

1. The Tenasserim valley.
2. The Theinkun valley.
3. The Leinya valley.
4. The Pakchan valley.

**Composition.**—The Tertiary rocks in the Mergui district are composed of finely laminated shales, sandstones and conglomerates. They can be divided into an upper and lower group. The latter comprises soft, sandy, white shales with plant remains, ferruginous sandy shales with ripple marks at the base and black carbonaceous shales with thin irregular layers and lenses of lignite. Resinous lignitic coal is intercalated at the top of the lower group. The upper group consists of white or

grey, soft, friable sandstones, followed by a ferruginous brown variety, whilst gravels associated with ferruginous conglomerate, containing boulders and pebbles of argillites of the Mergui Series, constitute the topmost member.

**Distribution.**—The Tertiary deposits of the Great Tenasserim valley, west of the Thawbaleik, have been largely eroded away, and only a few isolated outcrops remain. The valley and the Pakchan valley also have now been filled with recent deposits, mostly alluvium. In the Lenya valley the lower group is well developed near the confluence of the Pla-aw *chaung* with the Lenya river and the higher one near the villages of Htawphan, Bonkun and Nanka Hprao. Sethu Rama Rao estimated the thickness of the strata in the Lenya valley at 500 feet. The strike of the beds is generally north-south, with variations from 30° west of north to 30° east of south, coinciding roughly with the general strike of the country. They dip at low angles of from 3° to 5° in the centre of the valley, rising to nearly 30° on the flanks.

P. N. Bose examined the Tenasserim valley and proposed the name of Tendau Series for the Tertiary deposits of this region. They consist of shales and sandstones with coal seams below and conglomerate on the top. The shales in the proximity of coal assume darker colours. The conglomerate is coarse, and the pebbles, consisting mostly of argillite and slate from the Mergui Series, and which sometimes attain a diameter of one foot, are sub-angular in shape. The interbedded sandstones are massive, soft and false-bedded.

According to P. N. Bose these deposits, which were laid down in a lake-like expanse, are of shallow-water origin, and they were derived from the disintegration of the adjoining rocks. These rocks form a syncline, and their strike is north-east—south-west with dips varying from 20°–40°. They rest unconformably on the Mergui Series, which have undergone much greater disturbance than the overlying Tertiary deposits.

## Oil Shales, Amherst District.

Late Tertiary deposits, similar to those described above, occur in the Amherst and Mergui districts. But instead of

containing coal-measures, or rather lignites, they carry oil-shales and occur in synclinal basins in the river valleys, resting unconformably on the older rocks. In the Amherst district they are surrounded on most sides by Eozoic gneiss and schistose quartzites. Fish remains, shells of gastropods and impressions of dicotyledonous leaves occur in them.

**Occurrence.**—The main Tertiary basin containing oil-shale occurs in the broad open valley of the Mepale River enclosed between the Choehko *taung* and the Dawna range. This basin, which is a structural one, connected with the system of folding of the rocks, lies entirely in British territory and is called the Htichara basin; while the others lie partly in Burma and partly in Siam. In the Htichara basin eight distinct oil-shale seams have been found, and boring operations have shown that the shales are unusually persistent in their lateral extension. The Thaungyin river, which forms the boundary between Burma and Siam, shows in various places exposures of oil-shale. There is a basin of Tertiary rocks south of Myawaddy which Dr. Cotter referred to as the Phalu basin, while the second one lies to the north of Myawaddy and was named by the same authority the Mesauk-Methalaun-Melamat basin. It is not certain, however, if these two basins join up in Siam.

**Composition.**—Dr. Cotter divided the Tertiary rocks of this region into a lower and an upper division. The former group, which is extensively developed, consists of sands and boulder beds, while the upper group comprises shales with oil-shales. The lower division forms a ring all round the Htichara basin, and it also occurs west of Phalu along the Forest Reserve boundary. The sands are generally loose and current-bedded, and, according to Dr. Cotter, resemble those of the Irrawaddy Series, but fossil wood, though present, is sparsely distributed in them. The sands contain pebbles and boulders of the Archaean rocks, and they are smaller near the top of the sands and are larger at the base. But in several localities enormous boulders, sometimes measuring eight feet in diameter, are found. In places the beds consist of gravels or loosely consolidated conglomerates, grading into pebbly sands or sands of more homogeneous type.

In two localities, not far below the top of the basal sands,

reefs of fresh-water limestone are found. At the first locality, which is $1\frac{1}{2}$ miles east-north-east of Htichara village, and where the limestone is partly silicified into chert, abundant fresh-water shells were found. Dr. Annandale identified gastropods belonging to the families *Melaniidae*, *Viviparidae* and *Unionidae*.

Dr. Cotter states that the vegetation on the two groups is entirely different, and that the basal sandy group is overgrown by an open dipterocarp forest, while a dense growth of bamboos covers the shale country. The basal sands group passes upwards conformably and somewhat gradually into the oil-shale group. The distinction between the two groups is well marked in the Htichara basin, but in the other two basins sands are frequently associated with the upper shale group.

**Oil-Shale Group.**—The upper group consists predominantly of clay and shale, but with subordinate beds of sandstone. Thin beds of both a pure and an impure limestone occur north of Myawaddy, but they are less common in the other two basins. The limestone contains traces of shells of Melaniids and Viviparids and is undoubtedly a fresh-water deposit. The shales have yielded remains of a teleostean fish, dicotyledonous leaves, one fern leaf and a specimen of a spider.

Oil-shale is abundantly interbedded with the lower part of the shaly group. It is easily recognisable by its toughness, also by the fact that it can be cut into shavings with a knife, by its dark grey or brown colour, and especially by the peculiar smell given out when a small splinter is heated. The barren shale crumbles to powder easily, and there appear to be all grades of shale present, ranging from completely barren shale to high-grade oil-shale. As observed by Professor Gregory, a thin section of the rich material of the oil-shales is seen to consist of a base of a clay containing quartz grains and an organic material which is yellowish to brown by transmitted light and which serves as the kerogen. Dr. Cotter says that no trace of lignite was found in these beds. Two thin bands of gypsum, one inch and half an inch thick respectively, were observed in one locality.

**Mode of Origin.**—To the author it appears that these beds were laid down in fresh water where organisms, mainly

gastropods and fish, were rather common. These on destructive distillation yielded the oil-shale. The vegetable matter in this case was confined only to a few leaves, and this seems to be the reason why coal-measures are absent from this formation.

**Structure.**—These deposits form synclinal basins with gentle dips varying from 15°–20°. A dip of 30° is rather exceptional and there is a certain amount of undulation in the strata. According to Professor Gregory the beds are not infrequently well-jointed, and they have been broken by many small faults. Some of the bore cores show small parallel faults with a throw of an eighth of an inch. The faults are often in parallel series, and some form troughs in which the faults are either normal or over-thrust on both sides. The reversed faults were probably caused by the subsidence of the beds down the sloping sides of the lake. In some cases the beds have been buckled into small wavy folds.

**Age.**—The fossil evidence both of gastropod shells and plants, *Dipterocarpophyllum gregoryi* and *Ficophyllum burmense*, indicates a late Tertiary, possibly Pliocene age for these deposits, which is also rendered probable by the stratigraphical evidence, for the beds have not been disturbed by the earth-movements which affected Burma in the Lower and Middle Tertiary period.

## Oil-Shales, Mergui District.

According to Sethu Rama Rao the Upper Tertiary beds exposed along the Lenya valley resemble the oil-shales of the Amherst district described above. They consist of greenish shales, buff sandstones and sandy shales. The strata are folded into anticlines and synclines, the topmost beds being composed of white quartz pebbles. The shales exposed near Bonkun and Htawphan on the right bank burn with a bright flame, emitting odorous fumes when heated in a Bunsen burner.

Vinayak Rao examined the oil-shale outcrop of the Theinkun *chaung*. The oil-shales exposed in this valley are of a laminated dark coloured variety, passing down into light reddish shales. The Tertiary strata of the Theinkun valley are exposed for more than 8 miles, with a width of outcrop of about a mile and a half.

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# CHAPTER XXVI

## POST-TERTIARY DEPOSITS

THE Post-Tertiary deposits of Burma may be conveniently divided into (1) Pleistocene-sub-Recent and (2) Recent deposits. As examples of the former, mention may be made of the older gravels, clays, lake deposits, etc., which are undergoing denudation at the present day. The Recent deposits include all those eluvial and alluvial deposits that are now in the process of formation; for example, the newer river alluvium, clays, calcareous tufa, etc. These post-Tertiary deposits occur in patches and are scattered over wide areas, and hence, in each region, they have to be treated separately.

### Plateau Gravels.

The "Plateau Gravels" of Upper Burma consist of pebbles averaging one or two inches in diameter, but ranging up to boulders 18 inches in diameter in some localities, and are loosely aggregated in a deep-red ferruginous sand. Pieces of rolled fossil-wood and fragments of bones, as, for example, the femur of an elephant and tortoise bones, have been found in these gravels, which from their character appear to have been derived from the ferruginous conglomerates of the Irrawaddy Series. The pebbles are identical with those found in the Irrawaddian conglomerates and are mostly composed of quartz. Sometimes large slabs or boulders of hard, undisintegrated Irrawaddian ferruginous conglomerate occur within the Plateau Gravel. In some places they consist of very hard siliceous schist together with a large quantity of rolled fossil-wood.

Similarly, according to G. de Cotter, on either side of the Yaw river in the Pakokku district, boulders and gravel beds are seen some 300 feet above the present river level. Every large stream

in the Minbu and Pakokku districts is flanked by beds of old raised river-gravels. The old gravels of the Yaw river were derived from the rocks of the Arakan Yoma.

The most remarkable point about these old raised river-gravels is that they reveal that river gradients were universally steeper than at the present day. Nowadays the Irrawaddy at Yenangyaung transports coarse sand only; formerly it was able to carry pebbles of the size of an egg.

## Plateau Red Earth.

In Upper Burma the Plateau Gravel laterally becomes finer and finer, the pebbles becoming smaller and smaller, and more and more replaced by pebbly sand, until the deposit consists of a red ferruginous clayey sand, designated the "Plateau Red Earth" by Sir Edwin Pascoe. Its colour varies from a bright vermilion to a deep chocolate, but is usually a brick-red. It is of sub-aerial origin, which is proved by the absence of any bedding, the complete absence of fossils and its deeply ferruginous nature. It is generally unstratified, though sorting action is proved here and there by the occurrence of thin courses of fine gravel, coarser sand, or more clayey material, the former especially in the neighbourhood of any Tertiary conglomeratic bed: these are very thin—usually half an inch to one inch thick, and extend perhaps for two or three feet laterally.

**Mode of Formation.**—The upper portion of the Plateau Red Earth, which is bright red in colour, is a soil of lateritic nature, and the low-lying portions have been derived from this, either by the action of floods or by that of rain. Sir Edwin Pascoe writes: "Speaking generally, there is little doubt that the Red Earth is a lateritic soil and represents the land surface through which meandered the rivers which deposited the Plateau Gravel. It is impossible to assign anything but a sub-aqueous origin to the Plateau Gravel. The outcrops of dipping ferruginous conglomerates, very much harder than the loose sand-rock in which they lie interbedded, could not give rise under sub-aerial conditions to a flat plateau of gravel. . . . That the gravel passes laterally into the Plateau Red Earth is certain, and the two are equivalent and contemporaneous." After the close of the

Irrawaddian period deposits were formed upon the rolling uplands left by the rivers and floods of this period; these uplands are practically identical with those we see at the present day. Continued movement during the Irrawaddian period produced continued local contemporaneous erosion, and hence the Red Earths are found lying upon both the Pegu and Irrawaddian, though they are thicker upon the latter. By the process known as "laterosis" a red surface would be formed, and this process seems to be going on even to-day on some of the terraces of Mount Popa. It is not formed on steep slopes, and would, therefore, be limited mainly to the plains, and would be liable to be developed on sufficiently level hill-tops, so that we should have practically the same deposit occurring at different levels. Rain would to some extent sort its components and redistribute the material, while meandering rivers would carve out the pebbles from the conglomerates and produce the Plateau Gravel; floods would carry the smaller pebbles farther afield to mix with the red earth. According to Sir Edwin Pascoe the non-committal term "earth" is perhaps more suitable for a deposit formed in such circumstances than "alluvium" or "silt." The average thickness of the Plateau Gravel varies between 5 and 18 feet, but in places it may be less or may be considerably more. The Plateau Red Earth is generally quite thin, with a probable average thickness of 3 or 4 feet; but in places, especially in low-lying situations, it may be as much as 30 or 40 feet thick. These Plateau deposits were formed before the establishment of the details of the present drainage, though its main features had been already carved out. But "laterosis" is still going on, especially in the Dry Zone.

## Older Alluvium.

Theobald divided his "Older Alluvium" into (1) an upper and (2) a lower portion. The latter consists of sand and coarse gravels overlain by the older alluvial clay, and transported from some distance and containing large masses of silicified wood. The former comprises the newer alluvium building up the deltas of the Sittang and the Irrawaddy, and will be described later. The composition of the sand or gravel varies with the locality.

At Nyaungdon, at the top of the tideway, this bottom bed consists of clean sand with a few small quartz pebbles sparingly dispersed here and there through it. Higher up the river, a few miles above Monyo, on the opposite bank, a large stretch of gravel and boulders is exposed, which according to Theobald, is about the lowest point to which these very coarse gravels reach. Above this point coarse gravels are generally overlain by the clay, and exposed only where it is cut through, an excellent example being seen in the steep cliff opposite Prome. Here the gravel is some 30 feet thick, and its surface is not less than 60 feet above the flood level of the Irrawaddy. The gravel consists of well-rounded lumps of the hardest siliceous schists with a good deal of fossil wood, equally well-rolled and rounded. Two or three inches may be taken as the average size of the large and more plentiful ones, but a few larger ones than those also occur.

**Pegu Yoma.**—Similarly along the skirts of the Pegu Yoma a broad belt of sandy deposits, lateritic in places, occurs occupying the position of, and replacing the coarser gravels to the west. These sandy deposits acquire great importance to the south, where the Pegu Yoma sinks down and the Tertiary deposits forming it are concealed underneath this detrital talus for about 30 miles north of Rangoon.

**Henzada and Bassein Districts.**—Similarly, east of Ngaputaw on the Bassein river, a considerable area is occupied by these arenaceous deposits, as also in the northern portion of the Bassein district. A considerable tract of foothills skirting the Arakan Yoma is composed of gravel and sand of considerable thickness. Similar gravels were observed by the author [1] in the Henzada and the Bassein district lying to the south. Here the Plateau Gravel consists mainly of siliceous pebbles interspersed in finely disintegrated material, approaching coarse sands. The pebbles are generally small, less than three inches in diameter, but in places boulders exceeding a foot or more are not wanting. Where the Plateau Gravel caps the Sitsayan Shales a little clay also is intermixed with the sand. Sometimes hard boulders of laterite, with siliceous pebbles, are also to be seen. In the area examined by the author the siliceous pebbles were derived from the older formations, as water-worn pebbles of these rocks are

[1] *Journ. Burma Res. Soc.*, vol. xvi, 1926, p. 179.

definitely seen in the Plateau Gravel. They consist largely of pebbles of Nummulitic sandstones of various colours, and black, hard, indurated shales, sandstones, quartzites and quartz grits belonging to the Negrais Series. Subangular pieces of quartz are also found, which have been derived from the neighbourhood of the serpentine intrusions. They generally overlie the Sitsayan Shales unconformably. But they are also seen abutting against the Nummulitic Sandstone Series and occasionally against the Negrais rocks. No fossil wood was observed in the Plateau Gravel in this region. The gravel is generally undisturbed, but at one or two places it is inclined, indicating that it had been affected by the Pleistocene earth-movements.

**Tavoy District.**—In the open, upper valley of the Tavoy river, above Kaleinaung, the river is now cutting down through slightly consolidated, horizontal sands resting on coarse conglomerates, forming cliffs about 20 feet in height. At the head of the lower portion of the valley near Doodaung (Kadutaung), similar conglomerates occur as bars across the streams, and elsewhere are probably widespread, but concealed by later accumulations. It is possible that the coarse boulder conglomerates, upon which Tavoy civil station is built, are of the same period, though they may equally well be of earlier age; they carry both cassiterite and gold, and present difficult problems, such as the transport of such large fragments to the centre of flat and open valleys far from hills and swift-flowing streams. The cassiterite and topaz-bearing gravels, with a white clay matrix, which are profitably dredged on the Hindu *chaung* (a tributary of the Tenasserim), are also most probably of the same age, though they cannot be defined exactly. An elephant's tooth dredged from the tin-bearing gravels is closely allied to those of the modern Siamese elephant.

Exposed on the banks of the Tavoy river, between tide limits near Tavoy town, are gently inclined clays overlain by recent alluvium, now in progress of deposition. Certain fossil crabs preserved as curiosities in the local monasteries are believed to have come from these clays, and belong to species now living. The age of the clays is mostly sub-Recent.

**Mergui District.**—The older alluvium in the Mergui district is restricted to the larger valleys, such as those of the Tenasserim, the Lenya and the Pakchan rivers. According to Sethu Rama

Rao,[1] it consists of beds of ferruginous sandstone and conglomerate, gravel and pale-white clays. Some of the beds bordering the Tenasserim river consist of impure kaolin transported by streams flowing from the slopes of granite ridges. The thickness of the older alluvium ranges up to 60 feet, and the beds are sometimes gently inclined in contrast to the newer alluvium, which is always horizontal. Areas suitable for dredging tin are usually situated on the older alluvium.

### Uru Boulder Conglomerate.

Deposits similar to the Plateau Gravels of Upper Burma occur in the north of the Myitkyina district, and the Hukawng valley ; in the former area they were named by the author the Uru Boulder Conglomerate,[2] which had so far been taken to be alluvium of Recent age and had been mapped as such by Dr. Bleeck. The best exposures are seen in the neighbourhood of Hpakan, Mamon, etc., in the Kamaing Subdivision of the Myitkyina district. The conglomerate consists of water-worn boulders of all sizes, ranging from a few inches to several feet in diameter, embedded in red earth, but occasionally in sand-rock. Its thickness must be considerable—about 1,000 feet in places ; cliffs over 300 feet high composed solely of this conglomerate are fairly common. As this is the latest formation, except the modern alluvium, of the region, it includes boulders of almost every older rock ; these comprise altered peridotites, and all varieties of serpentine, rhyolite, siliceous breccia and quartz (colourless, pink and smoky). Boulders of crystalline schist are very common—mica-schist, quartz-schist, glaucophane-schist and anthophyllite-schist. Boulders of granodiorite, diorite and epidiorite also occur. Small boulders of chromite, haematite and limonite are occasionally observed. This formation is worked for boulders of jadeite.

It appears that the area has been affected by earth-movements subsequent to the Pleistocene period, since in places low dips—seldom exceeding 10°—are seen.

This jadeite-bearing conglomerate must have been deposited partly by the Uru (Uyu) river or its bigger predecessor, but more largely by the torrents flowing into it from the hills.

[1] *Mem. Geol. Surv. Ind.*, vol. lv, 1930, p. 33.

[2] *Rec. Geol. Surv. Ind.*, vol. lxii, 1929, pp. 112-113, and *ibid.*, vol. lxvi, 1932, p. 88.

## Tanai Hka Boulder Conglomerate.

Similar boulder conglomerates occur farther north in the Hukawng valley, and were examined by the author between Kaidu Ga (26° 14′, 96° 59′) and Warawng (26° 11′, 96° 58′). It consists mostly of disintegrated boulders of quartz-, mica-, and graphite-schists, etc., of varying sizes, embedded in reddish or yellowish soil. It was traced as far as Ngagattawng (26° 11′, 97° 3′), where the intercalations of sand in the conglomerate are washed for gold. In the opinion of the author both the Uru Boulder and the Tanai Hka conglomerates are representatives of the Dehing conglomerate of Mallet [1] in Upper Assam.

## Gem Gravels of the Shan States.

In the Northern Shan States gem gravels occur in old river terraces. The more important of these are the ruby-bearing gravels of the Mogok valley and the surrounding district, the tourmaline gravels in the Mông Löng sub-State, and the gravel terraces in the valley of the Nam-Tu.

## Gem Gravels of Mogok.

A complete description of the gem gravels of the Mogok valley is given by Barrington Brown as follows : " In the larger valleys of the district there are extensive deposits of alluvial matter consisting of clay, gravel, and sand, which have been laid down by the stream flowing through them. The materials of these vary in different portions of the same valley, being in the upper part of Mogok composed of a brown sandy loam resting upon coarse gravel, beneath which is an admixture of clayey materials containing gravel and sand, together with many rounded blocks of gneiss. In the lowest portion of the gravel and sand rubies and quantities of garnets are found. This rests upon an under-clay which, in places, is a white floury kaolin containing white mica, the result of the decomposition of the bed rock.

" Lower down the valley in front of Mogok the thickness of the top clay is from 15 to 22 feet, and the ruby-bearing sand and

[1] *Rec. Geol. Surv. Ind.*, vol. lxv, 1931, p. 79. *Mem. Geol. Surv. Ind.*, vol. xii, 1876, p. 30.

gravel beneath varies from 5 to 7 feet. Beneath this comes a stiff, yellowish under-clay containing a few water-worn pebbles and rounded blocks of gneiss. It is difficult to say of what the remainder of the deposit is composed after the under-clay is reached, for the miners cannot be induced to dig deeper than the base of the ruby-bearing sand, the under-clay being soft and dangerous to sink through, its weight breaking their light timbering.

"After washing the sand for the rubies they contain, the gravel remaining is composed chiefly of fragments of quartz, gneiss and pegmatite, amongst which are spinel, garnet, tourmaline and rock crystal." A detailed section of the alluvial deposit examined has also been given by B. Brown.

### Namhsuhka Ruby Gravel of Môug Löng.

An old river terrace deposit occurs in the valley of the Nampai, about 15 miles to the south-west of Môug Löng (Mainglon) and at the junction of the small stream, Namhsuhka, with the Nampai, also known in its lower course as the Maddya River. Here the alluvial deposits consist of coarse and fine gravels, layers of big, well-rolled boulders, and tough, brown, gritty clay, which contains numerous angular grains of quartz-rock. The different constituents were deposited without any sorting, which proves that they were laid down by a torrent and not by a large stream. The pebbles and boulders consist chiefly of milky quartz-rock; those of gneiss or granite are very scarce; there are occasionally some specimens of a black or blue siliceous shale, but no trace of limestone. It is in the sands or gravels that the rubies are found, not in the clays. The deposits do not form a continuous layer along the banks of the stream, but are found in isolated places which are suitable for their deposition and preservation, thus forming pockets of limited horizontal extent, and also hardly reaching higher up than 50 or 60 feet above the lower water level.

### Tourmaline Gravels of Môug Löng.

These tourmaline gravels form another river terrace deposit situated higher up in the valley of the Nampai, and found

along both sides of it, extending for about five miles eastwards from a point some two miles north of the town of Mông Löng. The boulders and gravel deposits reach (according to Dr. Noetling) a height of about 200 feet above the river, and consist of conglomerates and red clay. The conglomerates consist mostly of well-rounded, smooth pebbles of quartz-rock of various sizes, from small grains up to the size of a man's head and over. Other rocks are scarce, and only occasionally a small pebble of blue siliceous shale, or rotten schistose sandstone, is found. Well-rounded pebbles of black tourmaline approaching the size of a walnut are quite common. These have sometimes their original crystal-shape preserved still, but they are always much water-worn. Red tourmaline occurs very sparingly, as does rock crystal and agate.

The monotonous composition of this conglomerate proves that the pebbles were derived chiefly from gneissic and granitic rocks. The pebbles are cemented by a coarse gritty clay of yellowish colour, and the deposits form a very compact hard mass. The conglomerates are slightly auriferous.

The conglomerates are invariably covered by a layer of tough red clay, not particularly gritty, but containing numerous angular grains of quartz and felspar. The clay does not show any sign of bedding and is uniform from top to bottom; its thickness is very variable. In places it measures as much as 50 feet, while in others it ranges between 15 and 20 feet. La Touche is of the opinion that such coarse deposits as these could not have been accumulated on the bed of a lake, as suggested by Noetling. The clay, which is seen overlying the gravels, has none of the appearance of a lacustrine deposit, but is the same as that which covers both valley and hill-slope everywhere in the vicinity.

## Prehistoric Remains and Fossils from the sub-Recent Deposits.

Many of the alluvial flats of the Northern Shan States have been found to contain considerable numbers of stone implements and bronze fish-hooks, probably of Chinese manufacture, when the gravels were dug and washed for gems. Pieces of chipped

flint are frequently met with in some localities in the Plateau Gravels and "Plateau Red Earth." The implements found probably correspond to those recovered from the lateritic deposits of Madras. The specimen of the Pleistocene *Elephas antiquus* from the right bank of the Irrawaddy opposite Mandalay also came from the Plateau Gravel. Certain fossil crabs preserved as curiosities in local "*pongyi-kyaungs*" (Burmese monasteries) are believed to have been obtained from the clays of the Tavoy river, as mentioned above, and these belong to species now living.

### Older Alluvial Clay.

The sub-Recent sands and gravels, described above, are underlain by an even older alluvial clay, which covers the greater portion of the deltas and the lower parts of the valleys of the Irrawaddy and Sittang rivers. It is in composition a very homogeneous, somewhat arenaceous clay of a uniform yellowish colour, in places assuming a more reddish colour than usual, and under certain conditions of exposure and weathering assuming an imperfect lateritic appearance superficially. This is usually seen in the sides of wells, and is indicated by the peculiar mottled appearance the rock presents owing to the irregular manner in which the peroxide of iron occurs. The whole deposit is very homogeneous, a little more sandy in some places than in others, and with occasional layers of sand irregularly dispersed through it; the only recognisable band possessing a distinctive character in being a dark layer, a few inches thick, but of wide distribution.

Lime in the form of "kankar" is usually absent from the alluvial clay; but where it is present it occurs in small concretions quite insignificant in amount, and never in the pseudo-stalactitic and tabular masses seen in the alluvium of Northern India.

In the region where this alluvial clay is markedly developed there lies below it a thick deposit of sand or gravel varying very much locally, and made up partly of the detritus from the nearest rocks and partly of gravel derived from more distant sources. At Nioungdon, at the top of the tideway, this bottom bed consists of clean sand with a few small quartz-pebbles sparingly dispersed here and there through it; and it is this underbed of sand which so greatly favours the abrasion of the

channel of the Nioungdon stream and is the indirect cause of the broad shallow, just below the junction of the stream with the Irrawaddy, which forms so great an obstacle to navigation.

## Laterite.

Laterite is a kind of vesicular clay-rock, composed essentially of a mixture of the hydrated oxides of alumina and iron, with often a large percentage of other oxides, chief among which is manganese. It is generally of a red colour, which is due to the presence of iron oxide. This deposit is not so widely distributed in Burma as in India. On the western side of the Pegu Yoma it is rather sparingly developed, while, on the east, laterite generally forms the high ground that extends up to the Salween.

Wherever laterite is met with it is invariably found to occur as a surface layer or capping upon the older rocks, irrespective of their age. In the Tenasserim division it covers the granite and the Mergui Series, and is specially well seen close to the sea-coast. In Lower Burma it occurs above the older alluvial clay and the Peguan and Irrawaddian deposits. In Upper Burma "the "Plateau Red Earth" previously described is lateritic in many places. Farther north, laterite is found capping igneous rocks like serpentines and volcanic rocks.

The origin of laterite is attributed to a variety of causes, and no one theory seems to be satisfactorily applicable to all cases. Theobald proposed the term "laterosis" to imply the conversion of any suitable rock into laterite by the addition of iron, or the formation or development in it, through atmospheric action, of the hydrated peroxide of the metal, so familiarly seen in the glaze which covers all the lateritic rocks whether the iron be extraneously introduced or originally contained in the rock.

According to Dr. C. S. Fox the conditions favourable for the development of laterite are :

(1) A tropical and subtropical climate subject to alternating wet and dry seasons.

(2) An elevated level or gently sloping land surface not subject to appreciable erosion.

(3) The exposed rocks must contain alumina ($Al_2O_3$) and ferric oxide ($Fe_2O_3$) in appreciable quantities.

(4) The rock must possess or develop under weathering a porous texture, and allow rain-water to percolate through it.

(5) The infiltrating water must remain in the rock pores for an appreciable period, but must eventually drain out of them.

(6) Infiltrating water must contain either acid or alkaline substances which react on the rock and allow electro-kinetic phenomena to develop.

(7) These annual processes must continue without cessation for about a million years.

Probably alkalinity of the ground-water is essential as this has the property of removing silica from silicates, and converting them into colloidal hydroxides.

Laterite proper, or primary laterite, is derived from igneous or metamorphic rocks, and is consequently confined to the Tenasserim and the adjoining regions. The enrichment horizons of the newer deposits are secondary laterites, or lateritites, and contain much lower percentages of metallic oxides than the laterites proper.

A comparison by Barrington Brown to show variation in chemical composition from south to north is as follows :

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Iron Oxide ($Fe_2O_3$) - | 47·3 | 32·2 | 16·2 | 5·4 |
| Alumina ($Al_2O_3$) - | 6·8 | 4·2 | 7·0 | 4·8 |
| Lime ($CaO$) - - | 1·4 | 0·1 | 0·1 | — |
| Soda ($Na_2O$) - - | — | — | 0·9 | — |
| Potash ($K_2O$) - - | — | — | 0·1 | — |
| Magnesia ($MgO$) - | 0·1 | — | 0·1 | — |
| Silica ($SiO_2$) - - | 37·6 | 6·1 | 70·7 | 78·2 |
| Moisture - - } Loss on ignition - } | 6·8 | 1·6 | 0·9 } | 11·6 |
| | | 5·3 | 3·9 } | |
| Phosphates ($P_2O_5$) - | — | 0·03 | 0·1 | — |
| | 100·0 | 99·8 | 100·0 | 100·0 |

1. Rangoon Insein.
2. Tuchaubg, Zigon, Tharrawaddy district.
3. Paungde, Prome district.
4. Hmunsa, Red Beds, Allanmyo, Thayetmyo district.

It will be noticed from the above table that the percentage of metallic oxides decreases from about 54 at Rangoon to 36 near Zigon, 24 at Paungde and 10 north of Allanmyo in the

Thayetmyo district, proceeding from south to north. It shows lateritisation is most complete, or at any rate, most rapid, where the rainfall is heaviest. Strictly speaking, none but the Rangoon specimen is even a lateritite, the rest being only lateritic sands.

The laterite met with in the Thaton, Amherst, Tavoy and Mergui districts of the Tenasserim division is, as previously stated, found to occur capping the granite and the Mergui Series, composed mainly of argillites and phyllites. This is a region of heavy rainfall and luxuriant vegetation. The laterite appears to have been formed from the Mergui Series by purely atmospheric and organic action. The first stage in the process is the hydration and conversion of the ferrous oxides into ferric oxides; this is followed by the breaking up of the original rock along the joint planes and the slow change into a kind of compact lithomarge, mottled in shades of brown, red and purple. This is further broken up by the wedging-in of the roots of plants and is rolled down from the hill-slopes. The final product of all this decomposition and disintegration is a red clayey soil which is exposed at the surface. One feature to be noted here is that this type of deposit is generally confined to low-lying tracts.

**Mergui District.**—Farther south the lateritic rocks of the Mergui district include true laterites and also lateritites.

The olivine-basalt of Medaw Island is covered with a thin mantle of laterite, formed by the alteration of the mineral constituents of the rock. According to Sethu Rama Rao [1] the coastline fringing the mainland from Mathe to Salangin, east of the Turret Island, exposes large blocks of lateritic boulders, which have been formed by the alteration and disintegration of the sedimentary rocks of the Mergui Series, and the laterite has a vesicular texture. The quartzites and slates of the Mergui Series have pyrites as one of their constituents, and the alteration and subsequent hydration of the sulphide produces limonite for the lateritisation of the weathered argillaceous rock. Laterite formed by the weathering of granite occurs on many of the islands, such as Pulo Balaigh, etc.

Laterites of detrital origin derived from transported sediments occur at the foot of the dissected hills, at the debouchers of

[1] *Mem. Geol. Surv. Ind.*, vol. lv, 1930, p. 33.

the streams into the level country, and, as examples, laterites occurring east of Pelaw, in the valley between Kalatanyet and Mezaw, east of the Kyaukpya river may be mentioned.

Undoubtedly some of the laterite is being formed at the present day, while layers of it, already in existence and undergoing denudation, are of slightly earlier date.

### Correlation.

It seems certain to the writer that the Plateau Gravels, Plateau Red Earth, Older Alluvium, Uru Boulder Conglomerate and Tanai Hka Boulder Conglomerate were most probably all formed at about the same time, though the thickness of the last two is much greater than the similar deposits farther south. This discrepancy in the thickness will be easily accounted for when the situation of these deposits is taken into account. In the far north the torrents and hill-streams will be far more active than those of the uplands of the Dry Zone. Older laterite, again of Lower Burma, corresponds to the Plateau Red Earth, which, according to Sir Edwin Pascoe, has every appearance of an incipient form of laterite.

### Recent Deposits. River Alluvium.

Along the banks of the Irrawaddy and other important rivers of Burma there occur extensive stretches of alluvium or alluvial clay. This consists of a mixture of sand and clay, and sometimes shows signs of stratification. A not uncommon form is an alternation of sand layers and clay lenticles, very similar in appearance to the commonest type of the Pegu beds : in the case of alluvium this type usually shows pronounced current-bedding. Fossils are not found in the alluvium. Its predominant colour is usually a dull grey, but where it overlaps the Plateau Red Earth, as it does in the Salin sub-division, it becomes progressively more and more impregnated with oxide of iron derived from the older deposits, assuming a red colour which makes it difficult to draw any boundary line between the two. The river alluvium gives rise to a fertile paddy-growing land along the banks of the Irrawaddy. When the alluvium is clayey it is used for making pottery.

## Blown Sand.

At some spots on the Arakan and Tenasserim coasts there occur sand dunes which rarely attain any great height. They are generally found to the leeward side of extended tracts of sandy beach.

## Littoral Concrete.

Along the coast in the less sheltered tidal portions there occurs a deposit of calcareous sand composed of comminuted remains of living species of shell-fish and corals, consolidated into a more or less compact calcareous sandstone or ragstone, and displaying the same local variations as are seen in the deposits now forming along the Indian shores. It is a deposit of a very porous nature, and often yields a supply of very sweet water, being free from organic or other impurities, except perhaps in some places a little salt.

## Mangrove Swamp.

Where this littoral concrete does not form the banks of the tidal streams of the sea-coast, as in Arakan and Tenasserim, its place is taken by fœtid mud, or sand and mud of the mangrove swamps. In low-lying spots within the tide-way, whether mud or sand predominates, the deposit is equally offensive, the whole area being marked by a peculiar flora, and by the abundance of the strange crab, *Thalassina scorpionoides*.

## Calcareous Tufa.

Percolating waters carry away in solution very large quantities of the Plateau Limestone; when these come to the surface, either in the form of springs or rivers, they deposit their lime content as a result either of evaporation or of the loss of the carbon-dioxide which helps to keep the lime in solution. Therefore these tufa deposits attain very great thicknesses. Travertine deposits in the form of natural weirs or dams, a few inches to six feet or more in height, are often found in the beds of the rivers of the Shan States; according to La Touche they extend from bank to bank quite level with the crest as if they had been built

by human hands. Such bars are especially numerous in the Namma and Namyau above their confluence with the Namtu, and were probably established where changes in the nature or gradient of the river bed caused rippling, with consequent loss of carbon-dioxide.

## Peaty Deposits.

In the Northern Shan States in certain localities, usually on the gentle slopes surrounding the crest of a scarp, the water issuing from the springs, instead of depositing its burden of calcareous matter at once, sweeps away the covering of the Red Clay or perhaps prevents its formation. In such places a rank growth of aquatic plants and grasses springs up, and in time gives rise to the accumulation of a black soil resulting in peat. These peaty deposits are often of considerable dimensions, and may be easily recognised by the short green grass which covers them and by the absence of trees. They are common about Nawnghkio, the station on the eastern side of the Gokteik gorge.

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# CHAPTER XXVII

## IGNEOUS ACTIVITY IN RELATION TO TECTONICS

### I. Geographical Distribution of Igneous Occurrences.

THE igneous occurrences of Burma occur in groups along well-marked lines connected with the orographical features of the country described in Chapter I. Up to the present an erroneous idea of a *single* volcanic or igneous line in Burma has prevailed; several prominent geologists have repeatedly expressed the same idea, and widely divergent areas have been joined together to form one line. The author is of opinion that connected with the geotectonics of Burma there are at least five main igneous lines, as described in the sequel and depicted on the map, Fig. 19.

**Shan Plateau and two Igneous Lines.**—Connected with the warping of the Shan Plateau and its southern continuation are two igneous lines : an older and a younger. On the former lie the siliceous tuffs near the Lagwi Pass situated on the north-eastern frontier of Burma, the Bawdwin lavas and tuffs, and perhaps also the siliceous volcanic rocks of the Elphinstone, Maingay Island, etc., in the Mergui Archipelago. The younger line comprises the volcanoes of Teng Yueh in south-west Yunnan, the Loi Han Hun volcano in the Northern Shan States and some of the volcanoes of the Mergui Archipelago, including the basaltic flows of Medaw Island. This line passes farther southwards on to the Malay Peninsula.

**Edge of Shan Plateau.**—It is now well known that the edge of the Shan Plateau is formed by an important boundary fault which constitutes a major structural feature in the Burmese Malayan Arc of mountains. Along the edge of the Shan Plateau and the Tenasserim Yoma lie the lavas and dolerites of

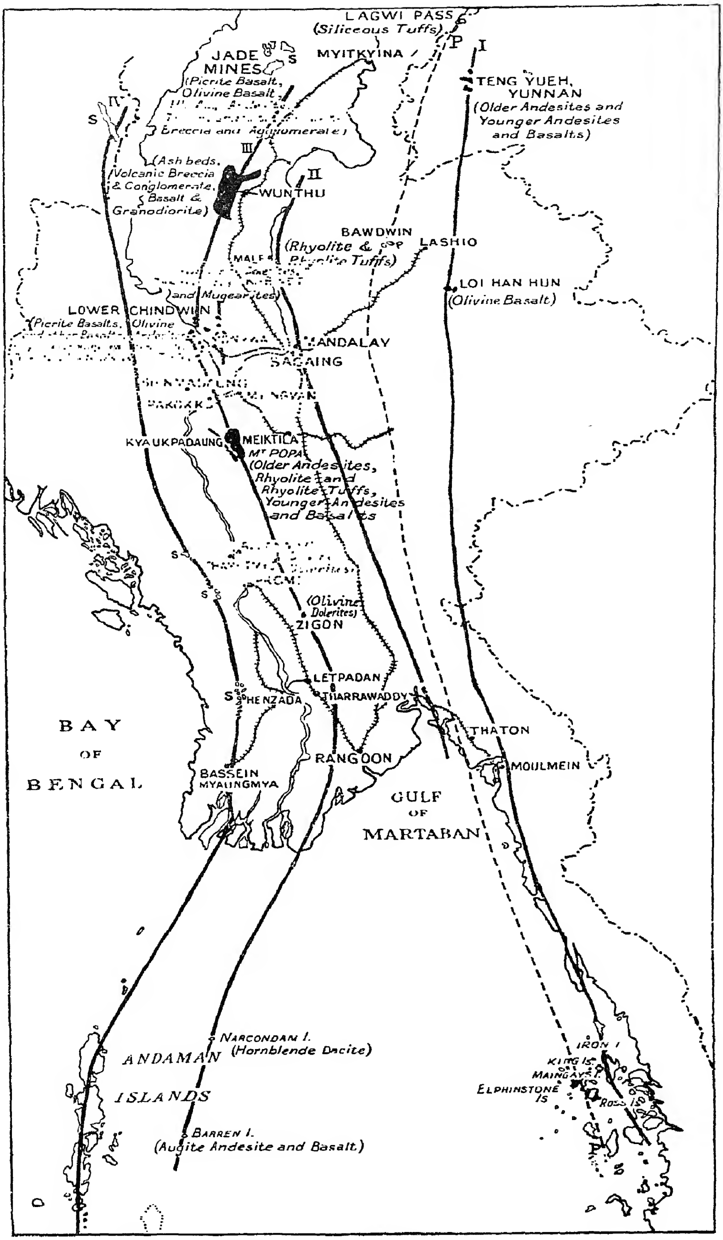


FIG. 19.—Map showing the five igneous belts of Burma. Broken line P-P passing through Lagwi Pass, Burma-Chinese frontier and Bawdwin, Northern Shan States and some of the outer islands of the Mergui Archipelago, shows the early Palaeozoic igneous occurrences. S-S denotes outcrops of serpentinised peridotites, with associated gabbros, diorites and volcanic rocks.

the Kabwet area, the Mandalay and Shwebo districts, and the rhyolites and rhyolite tuffs of the Thaton district, etc.

**Igneous Line of Central Belt.**—The igneous occurrences of the central line connected with the folding of the Pegu Yoma and their continuation into the northern hill ranges, comprise those of the Jade Mines area in the Myitkyina district, the Wuntho area in the Katha district, the Lower Chindwin, Shinmadaung, Mount Popa and the Prome and Tharrawaddy districts. The volcanoes of Barren Island and Narcondam are situated on the southern continuation of this line.

**Western Igneous Line.**—Connected with the upheaval of the western hill ranges is the belt of serpentinised peridotites, (p. 291), which runs from Java and Sumatra through the Andaman and Nicobar Islands in the south, to the frontiers of Burma and Assam in the north. Associated with these intrusions are volcanic lavas and tuffs found in almost all the centres of igneous activity. These lines have been depicted on the sketch map, Fig. 19.

## II. Important Orogenic Periods.

Excluding the solitary instance of igneous activity during the early Palaeozoic period, the study of the relationships of igneous activity to tectonics may be said to commence almost with the Tertiary or late Mesozoic orogenic history of the country. In all there are the following six important orogenic periods in the geological history of Burma which were accompanied by igneous activity :

1. Early Palaeozoic. The age of this orogeny cannot be fixed with certainty ;
2. Upper Cretaceous—early Eocene ;
3. Post-Eocene ;
4. Pliocene ;
5. Pleistocene ;
6. Recent and sub-Recent.

**Submergence of Crystalline Floor.**—After the formation of the crystalline floor, which is well exposed in the Ruby Mines tract of Mogok, the land was submerged and a huge thickness

of the unfossiliferous strata of the Chaung Magyi Series was deposited.

**Folding of the Chaung Magyi and Mergui Series.**—After the deposition of the Chaung Magyi and Mergui Series it appears that the country was upheaved and subjected to intense pressure. The strata are folded into narrow, closely compressed corrugations and are extensively faulted. The folding of the Mergui Series is sharper and more intense than that of the Moulmein Series, which is of a comparatively gentle type. In the case of the Chaung Magyis, however, evidence is forthcoming that they were thrown into folds and denuded before the deposition of the Naungkangyis (Ordovician). It is probable that there is an important hiatus between the Mergui and the Moulmein Series in Tenasserim.

**Bawdwin Lavas and Tuffs.**—Either towards the end of this period of deposition, or during the interval of upheaval and disturbance that followed it, some exhibition of explosive volcanic energy took place in the neighbourhood of Bawdwin, resulting in the emission of lavas and tuffs of an acid type.

**Siliceous Tuffs on Chinese Frontiers.**—Farther north on the Chinese frontier of Burma near the Lagwi Pass there occurred at about the same time explosive volcanic eruptions which deposited dark grey, fine-grained, siliceous tuffs, composed of highly angular quartz fragments surrounded by finer material containing much chlorite.

**Volcanic Tuffs and Agglomerates of Mergui Archipelago.**—The southernmost record of igneous activity along this line is to be observed on some of the islands of the Mergui Archipelago. This area, not unlike the Malay Archipelago, appears to have been another gigantic centre of igneous activity in Burma, where records of all kinds of igneous manifestation—plutonic, hypabyssal and volcanic—are preserved in many out of a total of about 900 islands. In fact, the Mergui Archipelago owes its origin to earth-movements, aided very substantially by igneous activity. The tectonics of the Mergui Archipelago have been discussed above, and the various lines depicted on Fig. 12. A. M. Heron is of the opinion that the foci of eruption which have distributed their débris widely through the rocks of the Mergui Series lie in the Maingay and Elphinstone Islands,

and hence he and Sethu Rama Rao consider these rocks to be of the same age as the Mergui Series.

**Acid and Basic Intrusions in the Mergui Series.**—The Mergui Series were similarly invaded by acid and basic intrusions which were explored by Sethu Rama Rao[1] near Talobusa in the Mergui district. According to him the junction is obscure, and it is difficult to state whether it is conformable or not. The acid bands are composed of felsites rich in quartz with a little biotite, while the basic rocks are rich in hornblende, pyrite and biotite with very little quartz. The rocks are undulating and gently folded, and the axes of the folds correspond with the strike of the sedimentary rocks of the district, *i.e.* 20° W. of N. to 20° E. of S.

It is difficult to fix the age of these intrusives. The original minerals have been much altered by metamorphism, and they have been subjected to severe crustal movements, including the folding of the Merguis. Their general appearance resembles that of gneiss. They were either intruded into the Merguis before the latter were folded, or are older than the Merguis.

## III. Igneous Quiescence.

When igneous activity round Bawdwin, etc., became extinct a remarkable period of quiescence followed. This interval of rest lasted throughout the whole of the later part of the Palaeozoic and Mesozoic eras of the earth's history. Though the geological record of the Northern Shan States for this period is fairly complete, not a trace of igneous activity has been discovered during these times. Burma proper was, of course, under the sea during these ages, and no landmass here existed.

During this vast interval of many changes in the distribution of land and sea, the evolution of plant and animal life took place. But it appears that earth-movements during this period were not severe enough to open fissures for igneous energy to manifest itself from beneath. It is believed that considerable earth-movements took place from time to time during the accumulation of the stratified deposits, but probably they were mainly of a tangential character, resulting in the

[1] *Mem. Geol. Surv. Ind.* vol. lv, 1930, p. 15.

folding and squeezing together of the strata, and it was not until near the close of the Mesozoic that great dislocations, which were more likely to accompany manifestations of igneous activity, began to develop.

### IV. Late Cretaceous—Early Eocene Movements.

As mentioned above, it was not until late Cretaceous or early Eocene times that the subterranean fires once more awoke to vigorous action. It was at this time that the Arakan Yoma with its continuations to the north and south were upheaved from the bottom of the sea in the form of a long narrow island.

About the same time the eastern hill ranges of Burma, including the Shan Plateau and Tenasserim Yoma, were lifted finally into a landmass which has persisted ever since. It was about this period that Gondwanaland broke up finally, and the Deccan trap lavas welled out through fissures in Western India. In brief, this must have been a very important orogenic period when vast changes of land and sea also occurred in other parts of the world.

### V. Serpentine Belt of Burma.

As an accompaniment of the late Cretaceous—early Eocene movements, intrusions of peridotites, picrites, gabbros and diorites took place in the Archipelagoes of the Andamans and Nicobars, the Henzada, Bassein, Prome, Thayetmyo and Minbu districts of Burma. Similar intrusions occur farther north in the Manipur and Naga Hills, in the Jade Mines area and the Hukawng Valley.

**Volcanic Eruptions in Early Eocene.**—Volcanic eruptions in the form of explosive activity, accompanied or immediately followed the peridotitic intrusions in most of the areas enumerated above.

**Emplacement of Peridotitic Intrusions.**—When the intrusions of peridotitic magma took place, movements both epeirogenic and orogenic were occurring on a tremendous scale all over the then Southern Continent of Gondwanaland. The rocks in which these intrusions occur are very tightly compressed, overfolded and faulted and have broken-backed anticlinals.

These intrusions have taken place either along or near fault lines marking weak interformational planes, or along tension cracks formed in the same series. The underground extensions of these intrusions appear to be in the nature of batholiths.

**Jade Mines Area.**—In the Jade Mines area the outcrop of peridotites and serpentines forms a well-marked plateau with an average elevation of 2,500 feet above sea-level. It is, therefore, probable that the magma erupted originally through a fissure. In places, however, the serpentine hills have a conical appearance, in other cases they form well-defined ranges.

In the Lawa tract of the Kamaing subdivision, Myitkyina district, the writer traced a narrow band of serpentine, which in places is highly brecciated, for several miles along the junction of the Crystalline Schists and the Older Tertiaries. It marked almost the position of the fault along which the big earthquake of the 28th January, 1931, and the numerous after-shocks took place. This was confirmed by the reversal of the direction of the earth sound on either side of the fault.

In passing, a brief mention of the intrusions of the jadeite masses into the serpentines of the Jade Mines area, may be made. The writer has found several outcrops of jadeite, which all follow linear directions. Both Noetling [1] and Bleeck [2] supposed that they occurred in the form of dykes. But a section exposed in the Kadondwin mine revealed that the jadeite intrusion into the serpentine may have taken place in the form of a sill.

**Hukawng Valley.**—The serpentine deposits of the Hukawng Valley are similar in their mode of occurrence, being in reality only a northern continuation of those of the Jade Mines area referred to above.

For the position of the serpentine intrusions reference may be made to the geological map of Burma, Plate XXIV.

**Naga Hills.**—In the Naga Hills, Pascoe [3] mapped a few bands of serpentine, which have a N.E. to S.W. trend, coinciding with the general strike of the country. The bands are most probably in the form of sills. Some of them occur in the Makwari Beds,

[1] *Rec. Geol. Surv. Ind.* vol. xxvi, 1893, pp. 26-31.
[2] *Rec. Geol. Surv. Ind.* vol. xxxvi, 1908, pp. 255-256.
[3] *Rec. Geol. Surv. Ind.* vol. xlii, 1912, pp. 254-264.

while others are found along the junction of the Chimi conglomerate (Cretaceous) and the Makwari Beds, while a few are intrusive into the Disang Shales (Cretaceous) which have been correlated with the Negrais Series of Theobald.

**Manipur Hills.**—In the Manipur Hills the serpentine forms a long dyke about 32 miles in length which evidently was intruded along a fault in the Axial Series. R. D. Oldham [1] has marked on the map accompanying his paper another linear outcrop along the Axial-Nummulitic boundary. The rock occurs in dykes of varying sizes, the main axis of the intrusion forming a band some mile or two in breadth, which runs throughout the whole of the district examined in a general north and south direction. He states that it is further worthy of note that the mode of occurrence of this serpentine is the same as in Pegu; namely, that the serpentine outburst is confined not merely to the east of the main range, but to the neighbourhood of the eastern limit of the hill rocks.

**Prome and Thayetmyo Districts.**—Farther south in the Prome and Thayetmyo districts the serpentine masses have erupted along or very close to the Nummulitic-Negrais or Nummulitic-Axial Series boundary, again on the eastern slopes of the Arakan Yoma. Theobald,[2] however, has shown on his map a few outcrops of these intrusions in the Axial Series which the author thinks mark the site of tension cracks in the formation.

**Henzada and Bassein Districts.**—The serpentine intrusions of the Henzada and Bassein districts [3] occur in the eastern foothills of the Arakan Yoma, either on the important fault marking the Negrais-Nummulitic junction or very close to it.

**Andaman and Nicobar Islands.**—In the Andaman and Nicobar Islands these intrusions occur mostly on the eastern side of the islands. In the middle Andamans there is a solitary outcrop of serpentine that occurs about the central part of the island. The slopes on the eastern side are much steeper than those on the west, and Tipper [4] found that in the case of the North Andaman

[1] *Mem. Geol. Surv. Ind.* vol. xix, 1883, pp. 224-242.

[2] *Mem. Geol. Surv. Ind.* vol. x, 1873.

[3] *Burma Res. Soc. Journ.* vol. xvi, 1927, pp. 176-199.

[4] *Mem. Geol. Surv. Ind.* vol. xxxv, 1911, pp. 195-216.

Island this persisted as a submarine feature (see Fig. 20). He was of opinion that to the east of the island there is a fault, and that in the neighbourhood of the fault the volcanoes of Barren Island and Narcondam had erupted.

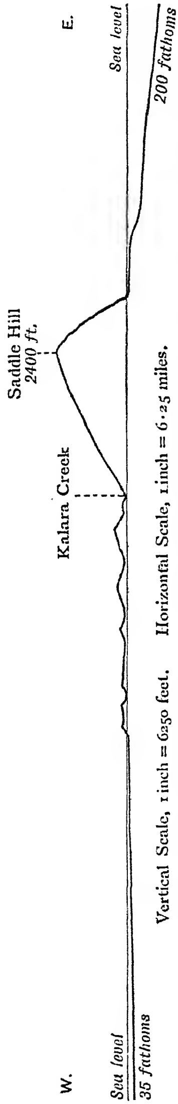


Fig. 20.—Section across the North Andaman Island through the Saddle Hill (lat. 13° 9' 30" N.), showing the steeper eastward slope continued as a submarine feature. Saddle Hill is composed of serpentine, the resistance of which to weathering has caused it to stand out so prominently.

## VI. Granites of the Eastern Hill Ranges.

The granites of Tenasserim and other districts farther north most probably also belong to the late Cretaceous—early Eocene period of igneous activity. The Malayan and Dutch geologists are decisive that they are of late Cretaceous age. The orogenic history of Burma supports such a conclusion, and these intrusions must have taken place when the Indo-Malayan arc of mountain chains was upheaved on the east. According to Sethu Rama Rao, after the deposition of the Mergui and Moulmein Series, there followed an upheaval by crustal movements, which caused folds (whose axes are parallel to the strike of the sedimentary rocks), and produced lines of weakness through which the granites were intruded in the form of large and small bosses.[1] Two types of granite, as described in detail later, have been recognised; one is a coarse porphyritic variety, devoid of tin, and the other is a biotite granite which is tin-bearing. The former is the older of the two. The age of this granite has long remained uncertain. L. D. Stamp [2] brought forward some evidence tending to prove the Mesozoic age of the granite of Tenasserim, a point which has

[1] *Mem. Geol. Surv. Ind.* vol. lv, 1930, p. 34.
[2] *Geol. Min. Met. Soc. Ind.* vol. i, 1926.

been lately confirmed by the Geological Survey of India. It is now believed by J. Coggin Brown [1] and others that the granites which stretch from Mergui into the hilly eastern edges of the Yamethin and Kyaukse districts are identical in composition, age and mineral association and are comparable with the granites of British Malaya, Sumatra, Borneo and the Dutch East Indies.

### VII. Post-Eocene Orogenic Period and Igneous Activity.

The third important orogenic period was some time post-Eocene, as seen in the Andaman Islands, where, according to Tipper, the Miocene beds, which rest unconformably on the Eocene rocks, are only slightly disturbed, so that the main portion of the movement must have ceased before their deposition.[2] Similar testimony was recorded by Cotter [3] in the Pondaung range. In the Maw Valley, near Tilin, there are deposits of gently dipping upper Tertiary gravels (Maw Gravels), a local facies of the Irrawaddian, resting upon the upturned edges of the Lower Eocene with strong unconformity and discordance. They prove that the Pondaung fold is very much older than the Maw Gravels, and therefore pre-Irrawaddian, and, perhaps, even lower Tertiary. During these movements the volcanic eruptions of Mount Loimye in the Kamaing subdivision, Myitkyina district, and of the Wuntho area in the Katha district perhaps took place.

**Mount Loimye.**—The tectonics of Mount Loimye are simple. The oldest rock in the history of this volcano is a greenish-black basaltic tuff which extends in a north-south direction for over three miles. It is undoubtedly an aqueous-bedded deposit, appearing in places to be interbedded with the Tertiaries, and to have participated in the folding of the area. North of the Loimye *hka*, gabbro was intruded into the tuff in the form of a composite sill or sheet. There is little doubt that the tuff was erupted originally along a fault running in a north-south direction which subsequently provided an outlet for gabbro

[1] *Rec. Geol. Surv. Ind.* vol. lx, 1928, pp. 79-83.
[2] *Mem. Geol. Surv. Ind.* vol. xxxv, pt. iv, 1911, p. 7.
[3] *Journ. Proc. Asiat. Soc. Beng.* vol. xiv, 1918, p. 409.

and also for the later rocks of the volcano. The existence of a fault along this line is supported by the presence of salt springs on it.

The Loimye volcano is apparently older than the outcrops of basalts and andesites seen in the neighbourhood of Namyong. Unfortunately there is no definite means of fixing the age of the fresh-water Tertiaries of this neighbourhood, but they bear a distinct resemblance to the Coal Measures in Assam. Percy Evans, to whom samples of the Tertiary rocks from this neighbourhood were sent for heavy residue analysis, came to the conclusion that they are comparable with the Barail Series (Eocene-Oligocene) of Assam.

**Wuntho Region.**—The tectonics of the Wuntho area are far from adequately known. Noetling[1] visited it in 1894, and according to him the most remarkable phenomenon within the area of the volcanic ash on the western side of Mainthong hill tract is that of salt springs. They are usually found in the bed of the streams where the brine oozes from the rock. If the situation of these salt springs is plotted on a map it is found that they occur along a line which runs about N.N.W., and are chiefly located at places where the erosion of the streams has cut across it. It is, therefore, highly probable that these salt springs follow a line of faulting, which seems in the main to run parallel to the cerussite vein. Looking at Noetling's map it appears that this fault is an important one, as it can be traced for about 60 miles. It is, therefore, not unlikely that the igneous rocks of Wuntho were erupted along this fault. The floor through which the igneous rocks were erupted is nowhere exposed in the area so far explored. The idea of the existence of the faults in this region is further substantiated by the occurrence of local earthquakes. The writer, while collecting accounts of the shocks felt on the north-eastern frontier of Burma, received several reports of shocks which had originated and were felt locally in the Wuntho subdivision of the Katha district. Some of them were indeed quite severe. It is, therefore, apparent that there are weak tectonic lines in this region which have not yet attained their equilibrium.

[1] *Rec. Geol. Surv. Ind.* vol. xxvii, 1894, pp. 115-124.

## VIII. Pliocene Contemporaneous Igneous Activity.

There is no doubt that at the close of the Peguan epoch orogenic movements occurred which folded the Pegu Series. Apparently these movements must have also operated for some time during the deposition of the Irrawaddians. Evidently accompanying these movements were manifestations of igneous activity, proofs of which we have in the Shwebo and other districts of Burma.

**Shwebo District.**—In the south-western corner of sheet 84 M/3 flows of basic volcanic rocks were found by L. A. N. Iyer [1] in the Kyauktan *chaung*, in the stream west of Yinyein (23° 18′, 95° 4′) and in the Hulyagyaung *chaung*. They are very numerous, vary in thickness from five to twenty feet and possess low westerly dips. Their presence among the softer sandstones and shales of the Irrawaddian Series often gives rise to waterfalls. They are associated with tuffs, and in one case at least bear interbedded bands of clay.

**Kabwet Area, Shwebo District.**—Passing eastwards we find similar evidence in the Kabwet area [2] of the Shwebo district. Here very decomposed lava, described by Dr. Stamp and the author as the "older lava," occurs interbedded with the Irrawaddians and is also involved in the folding. Where it was traced on the western side of the anticlinal fold it dips very steeply, but is much better displayed on the eastern side, where it forms a long and conspicuous scarp. It dips steadily at about 30° to the east and presents a long dip slope, often bare of soil and vegetation, and a steep, usually precipitous scarp slope.

**Mount Popa Area.**—In the Myingyan district these movements evidently continued throughout the Irrawaddian period right to its close; while in the Mount Popa area we have black basic tuffs and ashes interbedded with almost the highest of the Irrawaddian beds, of which the plateau, on which Mount Popa stands, is built. As was noted by Sir

[1] *Rec. Geol. Surv. Ind.* vol. lxv, 1931, p. 95.

[2] *Trans. Min. Geol. Inst.* vol. xxi, 1927, pp. 105-107.

Edwin Pascoe [1] and the author,[2] volcanic activity commenced towards the close of Irrawaddian times, but the later and larger flows of augite- and hornblende-andesites and the clastic material derived therefrom are in all probability post-Irrawaddian.

## IX. Pleistocene Orogenic Period and Igneous Manifestations.

The Pleistocene marked the next orogenic period in Burma, when the Irrawaddians were folded and faulted. During this diastrophic period volcanic and other igneous activity manifested itself in several centres in Burma, especially in the Central Belt and the Shan Plateau. It was at this time that some of the volcanoes of the Jade Mines area, the Lower Chindwin region, Mount Popa, etc., were active. The dolerites of the Pegu Yoma also were most probably intruded at this time. The olivine-dolerites, teschenites and olivine-basalts (mugearites) of the Mandalay and Shwebo districts were also erupted as a result of these tectonic movements. There is little doubt that some of the Teng Yueh lavas in Yunnan, and the basalt of the Loi Han Hun volcano in the Northern Shan States were poured forth during this period.

**Jade Mines Area.**—The volcanic rocks of the Jade Mines area can be classified as follows :

*A.* The Mabaw siliceous agglomerate.

*B.* Andesite and basalt outcrops in the neighbourhood of Namyong (25° 40′, 96° 25′).

The red siliceous agglomerate, which the writer has designated the Mabaw siliceous agglomerate,[3] begins near Sankha village and continues in a north-easterly direction for about three miles as far as the Moschen *hka*. The width of the outcrop does not exceed half a mile. It appears that the volcano burst through the floor of the serpentine, since lapilli of that rock, which sometimes attain the size of small blocks about 18 inches long, are included in the breccia. Moreover, the

[1] *Mem. Geol. Surv. Ind.* vol. xl, 1912, p. 45.

[2] *Trans. Geol. Min. Inst. Ind.* vol. xxi, 1927, p. 305.

[3] *Rec. Geol. Surv. Ind.* vol. lxiii, 1930, p. 101.

reddish colour of the paste confirms the view that it must have been derived from the soil or subsoil of the serpentine.

There is no doubt that the formation in question is interbedded with the late Tertiaries, since boulders of the Tertiary conglomerate are seen in the breccia itself, and a thin band of the Tertiaries is generally seen at the base of the breccia. Probably the eruption took place along the fault marking the junction of the serpentine and the agglomerate. This is confirmed by the occurrence of salt springs on the western boundary of the formation in question.

Several outcrops of andesites and basalts occur in the neighbourhood of Namyong. The volcanoes in each case have burst through the Tertiaries, which consist of soft sandstones with quartz pebbles and fossil wood, leaving little doubt that they cannot be older than the Irrawaddy Series. The Tertiaries have been thrown into anticlinal and synclinal folds, and most probably the lavas reached the surface along the axes of the former.

**The Lower Chindwin Region.**—The general trend of folding in the Tertiary hills lying to the west of the Chindwin river in the latitude of Monywa is north and south.[1] There are three lines of folding in the area (see Fig. 21):

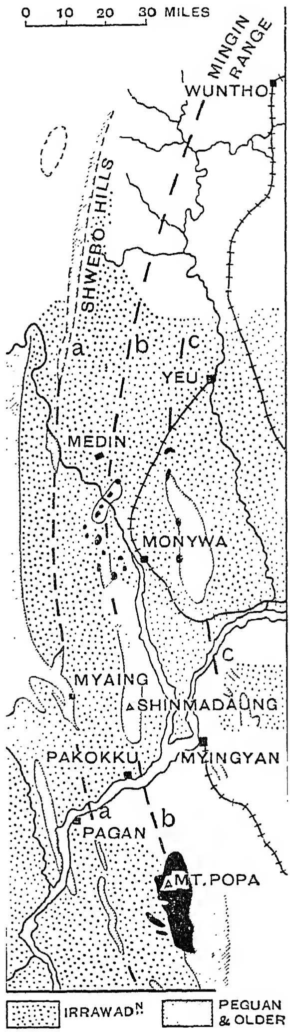


FIG. 21.—Showing the main tectonic lines in the central part of Upper Burma, and their connection with the igneous rocks of that region. Igneous rocks in black.

[1] *Trans. Min. Geol. Inst. Ind.* vol. xxi, 1927, pp. 149-150.

(*a*) The line of folding including the Medin and Myaing inliers of the Pegu Series is continued both to the north and to the south. Southwards it assumes a trend east of south and includes the inliers of Pagan, Ngashandaung and Yedwet: Northwards the trend becomes east of north and the line passes into the Shwebo Hills inlier.

(*b*) The fold line which passes through Mount Popa lies next to the east, and this when traced northwards from Popa is seen to include Shinmadaung and the explosive craters of the Chindwin. When traced still farther north it passes to the east of the Shwebo hills into the Katha district and possibly includes the volcanics of the Wuntho region (Mingin Range).[1]

(*c*) The volcanic occurrences in the hill belt to the east of Monywa, which run in a general direction of a few degrees west of north, appear to lie along an additional tectonic line to the east and add to the width of the belt of vulcanicity.

Summarising, the volcanic occurrences of the Lower Chindwin form a broad belt, about 25 miles in breadth, running in a north and south direction and closely connected with two anticlinal axes (*b* and *c* above). Fig. 21 illustrates these points.

**Shinmadaung.**—The majority of the igneous developments in the Shinmadaung inlier took place along the line of the main strike fault, and it would appear that they were determined partly by its presence. In general they lie on line (*b*) of the folding described above.

**Mount Popa Area.**—In the case of the Mount Popa area[2] the general strike of the volcanic hills is N.N.W.–S.S.E., corresponding to the anticlinal and synclinal axes of the neighbouring Tertiary rocks. Further, as seen in the volcanic rocks themselves, their axes of folding have the same trend. Two miles south of Sima and Shawdaw a very strong tendency towards anticlinal folding was observed by the writer. The eastern limb is well developed, while the western shows a scarp which may be due to faulting; very likely Mount Popa lies on the same fault. It is noteworthy that the lavas were erupted along the Pegu-Irrawaddian junction.

[1] *Rec. Geol. Surv. Ind.* vol. xxvii, pp. 116-117. See also *Mem. Geol. Surv. Ind.* vol. xl, part 1, 1912, p. 46.

[2] *Trans. Min. Geol. Inst. Ind.* vol. xxi, 1927, pp. 302-303.

There is a subsidiary line on the west, however, with the same general strike on which the Kyaukpadaung volcanoes are situated.

**Doleritic Intrusions in the Pegu Yoma, Prome Area.**—The general structure of the country into which the dolerites are intrusive, consists of anticlinal and synclinal folds. At two localities, viz., Lethadaung Myenethaung and Tondaung Myenethaung, the writer [1] saw dolerites as small sheets or sills intrusive along the bedding into the Pegu Series. In the latter case the Peguan rocks dip towards the south with an average dip of 30° and into them the dolerites have forced their way. At the contact the clays and sandstones are altered as a result of thermal metamorphism, the former having been converted into shales. The coral limestone has also recrystallised as a result of the same agency. Figs. 27 and 28 illustrate the tectonics of the area and the mode of intrusion of the dolerites.

**Tharrawaddy Area.**—The area mapped here consists of a big anticline with its axis running roughly east and west. The northern limit of this anticline is well exposed in the Kyaukpyu *chaung*, while southerly dips are to be observed near the igneous intrusions. It appears that the latter occur generally as small sills, intrusive along the bedding planes. This is clearly seen near the " Three Falls Hill " in the Ngayan *chaung*. Here the first waterfall is determined by baked shales, dipping south-west at the steep angle of 55°. The igneous rock dips sharply into the shales as a result of the jointing at right angles to the bedding. Then, at a distance of about 100 feet below, there is another waterfall in igneous rock dipping at rather high angles with the sedimentary rock. At a short distance below it the third fall occurs. It is again determined by rather steep beds of hard-baked shales dipping south-west. The shales show contact effects such as induration, bleaching and incipient development of contact minerals and spots. The doleritic sill intrusive into the shales and forming the three falls is depicted in Fig. 30.

The central intrusion of Kyaukyi *taung* appears to have forced its way near the crest of the anticline and may represent a small laccolite.

[1] *Trans. Min. Geol. Inst. Ind.* vol. xxi, 1927, pp. 333-336.

**Kabwet Area, Shwebo and Mandalay Districts.**—Farther eastwards, the dolerites and basalts of the Kabwet area are situated on the edge of the Shan Plateau. The tectonics of the region are comparatively simple. The Irrawaddian sands have been folded into an anticline on the west, followed by a syncline. The axis of the former is marked roughly by the main doleritic intrusion of Nattaung. The anticline is asymmetric: the dip on the western flank approaches vertical, while on the eastern flank it does not usually exceed 4°. Some of the doleritic intrusions seem to occur as sills.

*Basalts.*—The basalts, or the "Younger Lava," of the Kabwet area, as they were originally termed, are confined to the south of the River Irrawaddy, and form a roughly horizontal sheet, resting on the denuded edges of the folded Irrawaddian rocks. The eruption evidently took place through a fissure or fissures, and the lavas form a well-marked plateau, 24 square miles in extent. About lat. 22° 44′ N. the Irrawaddy makes a sudden and remarkable right-angled bend to the west, and flows westwards for about two miles before resuming somewhat more gradually its normal southerly course. The remarkable change in general direction in this region is determined by the presence of the lava plateau of Singu to the south, around the northern and western edges of which the river now swings. There can be little doubt that the lava was poured out across the valley of the river itself, and that the present course is comparatively recent.

The first thing which strikes one about the basalts is their remarkably fresh, unaltered appearance. Apart from the fact that the plateau is covered with a forest of tall trees one might be standing on a flow of lava scarcely yet cool. It is, therefore, probable that this eruption may have taken place in Recent times.

There is little doubt that the lava was erupted through fissures, almost marking the junction of the crystalline rocks (Mogok Series) of the Shan Plateau and the Tertiaries. As already remarked, this fault constitutes one of the major structural features of the Burmo-Malayan region. La Touche wrote: "It is to be observed that these ancient rocks were brought to the surface in Upper Tertiary times, since on the western

side they are in continuous contact with sandstones of that age. In fact, it is evident that the whole length of the western edge of the Shan Plateau is a fault scarp due to a great fault." [1]

**The Thaton District.**—Passing southwards along this line we have the rhyolites and rhyolitic tuffs of the Thaton district. The volcanic rocks here, from their north-south linear arrangement, appear to have been erupted along a strike fault in the sedimentary rocks produced probably as a result of folding and faulting of the Tenasserim Yoma, which are merely a southern continuation of the Shan Plateau. The ridge formed by the capping of lava also forms the foothills, or, in other words, the edge of the Tenasserim Yoma to the east.

As regards the age of the lavas, they have flowed over the sedimentary rocks which are presumed to be Permo-Carboniferous, so it can be said that they are at least post-Permo-Carboniferous in age. But from their freshness and from their great similarity to the rhyolites and rhyolite tuffs of the Mount Popa area, the Lower Chindwin and the Jade Mines region, it may be surmised that the Thaton lavas are contemporaneous with these, as to the post-Pliocene age of which there is not a shadow of doubt.

**Loi Han Hun Volcano, Northern Shan States.**—Passing to the Shan Plateau on the east we come to the volcano of Loi Han Hun in the Loi Ling range. It is very interesting to note that in the present state of our knowledge this is the first manifestation of volcanic activity in the Northern Shan States, after the outpouring of the Bawdwin lavas and tuffs. It appears that towards the close of the Tertiary period earth-movements were of a very extraordinary severity, and produced a series of cracks by which the whole of the plateau was dissected. It is these cracks that opened the way for the dormant energies lying below.

The volcano of Loi Han Hun, according to La Touche,[2] is a conical hill, the lower part of which is composed of Tertiary silts which are nearly horizontal, while the upper part is a dome-shaped mass of columnar basalt with dykes or wall-like masses of the same material radiating in all directions

[1] *Mem. Geol. Surv. Ind.* vol. xxxix, 1913, p. 352.

[2] *Rec. Geol. Surv. Ind.* vol. xxxvi, 1907, pp. 40-44.

from it, but most highly developed towards the west and north-west, where there may be another focus of eruption. The energy of the volcano appears to have been just sufficient to extrude the dome of basalt now forming the upper part of the hill and to fill the fissures surrounding it, no traces of a true cone built of ashes or tuffs being visible. The form of the volcano is similar to that of a volcanic plug.

The volcano seems to have been active in post-Tertiary times, as the lavas were erupted into the Tertiary silts which represent the highest deposits of that era, for they have been accumulated since the principal drainage features of the plateau were carved out, and all the fossils they contain are very recent fresh-water gastropods such as *Paludina* and *Planorbis*.

**Teng Yueh Volcanoes, Yunnan.**—Some of the volcanoes near Teng Yueh in south-west Yunnan were contemporaneous with Loi Han Hun, referred to above. Geologically, this part of Yunnan is simply a northern continuation of the Shan Plateau, and there is no doubt that the two regions were affected by the same tectonic movements. The volcanoes of Lao-Kuei-po, Tay-in-Shan and the Kung-po group described by Coggin Brown [1] and Burton are all believed to be of late Pliocene or Pleistocene age, when, according to the former author, the general orography of the district was almost the same as that of the present day. This is proved by the recent appearance of the craters and of the rocks themselves, by the fact that they have taken part in no serious earth-movements and are not tilted and folded. Further, in some cases they have been poured out over the late Tertiary lacustrine deposits of the valley, close to which they are situated.

**Mergui Archipelago.**—Passing southwards, the olivine-basalts of the Medaw Island form a little plateau and rest on the Mergui Series. Sethu Rama Rao said that "although a careful search was made, nothing resembling volcanic vents or necks could be seen." The writer visited the area in October 1926 and found that this occurrence showed great similarity to the olivine-basalts of the Kabwet area, referred to above. It is most probable that the flows of olivine-basalt were erupted through a fissure in the Mergui Series.

[1] *Rec. Geol. Surv. Ind.* vol. xliii, 1913, pp. 173-228.

## X. Recent Orogenic Movements and Igneous Activity.

There is considerable evidence to show that important orogenic movements operated during Recent times. There is unmistakable evidence of the recent uplift of land in the form of raised beaches on the Arakan coast and the Andaman Islands. Similarly, signs of Recent elevation are not wanting on the Malayan shores. Dr. Cotter, in his paper on the geotectonics of the Irrawaddy basin, has given many instances of Recent upheaval in the Irrawaddy valley. It must have been during Recent and sub-Recent times that the Plateau Gravels of Pleistocene age were folded and tilted. Similarly, the Uru Boulder Conglomerate in the Jade Mines area and the Tanai Hka Boulder conglomerate in the Hukawng Valley, both of Pleistocene to sub-Recent age, were found tilted at an average angle of 10°.

Some of the volcanoes of the Jade Mines area, the Lower Chindwin area, Mount Popa region, Narcondam and Barren Islands, all lying in the Central Belt of Burma, were undoubtedly active, as an accompaniment of these movements. The last-named volcano still smokes at times and was observed in actual eruption during the later part of the last century.

**Jade Mines Area, Myitkyina District.**—An example of volcanic eruption during Recent times is furnished by the olivine-basalt of the "1361" hill, about a mile south of Namyong. Here the upper slopes of the hill are built of basalt overlying late Tertiary rocks. It is evident that the volcano erupted when the present small drainage channels of this neighbourhood had been carved out, as the blocks of lava, a few feet in diameter, representing the broken flows, have a much greater extension along them, and are piled up wherever any little ascent commences. The writer is inclined to believe that the blocks of siliceous breccia seen in so many places in the area, and also some of the hornblende-andesites were erupted during Recent times.

**The Lower Chindwin Region.**—Farther southwards some of the flows, explosion craters, ash and tuff deposits are undoubtedly of Recent or sub-Recent origin. Most of them

are composed of soft, incoherent ashes, but in spite of that they present to-day an appearance as if they had only just been formed.

**Mount Popa Area.**—In the Mount Popa area igneous activity which commenced in post-Peguan times probably ceased only in Recent times. There may be some truth in the legend recorded by Bell which says that "according to tradition there was a great earthquake in 442 B.C. during which the great cone of Popa rose from the plains, but the native chroniclers leave no record of how long it was active and when it became extinct."

**Narcondam and Barren Island.**—Farther down on the same line lie the volcanoes of Barren Island and Narcondam. The latter has become extinct lately; but the former still smokes at times and was observed to have been in active eruption. Tipper is of the opinion that, to the east of Andaman Island, there is an important fault, on which these volcanoes are situated.

**Teng Yueh, Yunnan.**—On the eastern extremity of Yunnan the volcano of She-toe-Shan belongs to this category. Coggin Brown says "although She-toe-Shan has been quiescent within historical times, nothing could be more evident than its recent appearance. Erosion and denudation have up to the present made little impression upon it." The vegetation is very scarce, on account of the scanty soil on the lavas of She-toe-Shan.

## XI. General Emplacement of the Igneous Occurrences.

As explained below, some uncertainty prevails with regard to the early Palaeozoic igneous activity. In the east, and covering the site of the Shan Plateau, the Karenni Hills and Tenasserim, the land after the deposition of the Chaung Magyi and Mergui Series was upheaved and subjected to great disturbances, when the igneous activity occurred in the neighbourhood of Bawdwin, the Lagwi Pass and in the Mergui district, as explained below. After this phase of igneous activity, the whole of Burma, including the Shan Plateau and the Tenasserim Yoma, was under the sea, and, as mentioned elsewhere, it

was during the late Cretaceous—early Eocene period that the land-masses on the east and on the west were upheaved. In the latter region a belt of serpentinised peridotites is intrusive into the eastern margins of the mountain masses, though a solitary occurrence of serpentine in the Sandoway district in the Arakan Yoma is known. These hill-ranges mark the site of an important geosyncline, in all probability the continuation of the Himalayan geosyncline, towards the south. It seems, therefore, that these serpentine intrusions took place in the margins of the geosyncline, and mainly in the *eastern* arc, which had just begun to be upheaved. Since most of these serpentine intrusions occur on the eastern margin of the geosyncline it is perhaps reasonable to assume that the thrusts responsible for the upheaval of the land came largely from an easterly direction.

This belt in the north, especially in the Myitkyina district, widens considerably, as not only do the serpentine intrusions occur in the Jade Mines area and the Hukawng Valley, but they extend as far east as the neighbourhood of Myitkyina itself.

Volcanic rocks, mostly in the form of ash-beds, sometimes interbedded with Eocene sedimentary deposits, occur associated with almost every area of serpentine intrusions. This tends to confirm the conception of sub-aqueous igneous eruptions in the late Cretaceous—early Eocene period on the eastern margin of the rapidly shallowing geosyncline. Instances of this, which have been described above, occur in the Bassein, Myaungmya, Henzada, Minbu and Pokokku districts and the Manipur hills. The Central Belt, or Burma proper, was still under the sea, but we find vestiges of igneous activity during the Eocene period in the Shinmadaung hills in the Pokokku district, and it is likely that, during the Eocene period, an inlet of the sea extended in that direction, the intervening portion of which was subsequently covered by the Irrawaddian Series.

The precise age of the Wuntho and Loimye volcanics cannot be determined ; but it is known that in both areas the eruptions were initially sub-aqueous, and marked almost the middle of the northern portion of the Central Belt, which commenced shallowing and gradually rising from the north. It may be that these eruptions occurred either during Eocene times with

the others or during the next orogenic period (post-Eocene). The writer is, however, inclined to the former view.

It was only during late Tertiary times that the Burmese gulf, marking the site of the Central Belt of Burma, was gradually silted up. It is known to have constituted an important geosyncline, where deposits (according to Dr. Cotter) [1] with a minimum thickness of 43,000 feet were laid down. In the Jade Mines region, the Lower Chindwin and the Mount Popa areas, the igneous activity commenced under sub-aqueous conditions, but almost towards the end of the silting up of the gulf. These igneous occurrences lie on the centre of the geosyncline, and are connected with the axes of the various fold lines into which it has been thrown.

The margin or the edge of the geosyncline is marked by a boundary fault, where the eruptions of the Kabwet area, the Mandalay and Shwebo districts, and those of the Thaton district occurred. Here, again, we find igneous activity on the eastern margin of the rapidly shallowing geosyncline, as was noticed in the case of the Arakan Yoma and its continuation to the north. No igneous occurrences of this age are known from the western margin of the Central Belt.

The late Tertiary—Recent igneous activity connected with the Shan Plateau and its southern continuation seems to have been sub-aerial, and the location of the eruptive centres has been determined by one of the vertical faults crossing the plateau.

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2. Chhibber, H. L., "The Ancient Volcanoes of Burma" (Abstract), *Journ. Burma Res. Soc.*, vol. xvii, 1927, pp. 169-173.

See also the references given at the end of other chapters on igneous activity.

[1] *Journ. Proc. Asiat. Soc. Beng.* vol. xiv, 1918, p. 415.

# CHAPTER XXVIII

## IGNEOUS ACTIVITY (*Continued*)

## VARIATION IN TIME

### EARLY PALAEOZOIC IGNEOUS ACTIVITY.

### Rhyolites and Rhyolite Tuffs, Bawdwin, Northern Shan States.

REFERENCE to the earliest igneous rocks after the Archaean period has been made above. In the neighbourhood of Bawdwin and at certain other localities there are rocks of undoubted volcanic origin which consist mainly of tuff or ash-beds, but among them layers of true rhyolites are interstratified. The rhyolites, which are subordinate in bulk to the tuffs, are pink, brown or chocolate in colour and often full of clear grains of secondary quartz. In places they are much smashed and broken by fault planes, or, again, the rock may be exceedingly crushed and made up of angular fragments loosely held together, an indication of the great strain to which it has been subjected. Finer-grained varieties also occur, which are greyer in colour, with fewer and smaller shale inclusions and a greater development of secondary quartz. They exhibit the usual phenomena observed in acid glassy lavas, such as flow, spherulitic and perlitic textures and corrosion of the quartz phenocrysts. The groundmass is always crypto-crystalline and sometimes exhibits the peculiar structure of alternate light and dark areas under crossed nicols known as "quartz mosaic." The texture is exactly similar to that which occurs in some of the Malani rhyolites of Western Rajputana,[1] and in both instances the quartz phenocrysts are surrounded by a 'court' or closed area, the quartz of which is in optical continuity with that of the

[1] *Mem. Geol. Surv. Ind.* vol. xxxv, 1911, pp. 78-90.

phenocrysts. The Malani rhyolites are pre-Vindhyan in age; but a similar texture has been noticed by Dr. Fermor [1] in the lavas of Pavagad hill in the Bombay Presidency; these are of late Cretaceous age. The presence of this texture cannot be taken, therefore, as evidence of a similarity in age between the Bawdwin and Malani rhyolites; but in other respects, such as the preponderance of quartz phenocrysts over those of felspar, the absence of plagioclase felspar and of augite, they resemble each other and differ from the lavas of Pavagad hill, as described by Dr. Fermor. Since the Bawdwin rhyolites are certainly pre-Ordovician, there is probably not much difference in age between them and the Malani rocks.

Tuffs.—The tuffs, which form by far the greater part of the bulk of the rocks at Bawdwin, resemble the rhyolites superficially under the microscope, but are distinctly clastic in origin, and sometimes contain fragments of the lava. They have suffered extensive metamorphism, with the result that it is not easy to demarcate the tuff and the rhyolite zones. At the surface they are usually soft and of light greyish colour owing to kaolinisation. Underground they are darker in colour and often honeycombed, though, here and there, their original nature is still further masked by the chemical changes they have undergone through the action of mineralising solutions. This is especially seen near the mines at Bawdwin. Secondary quartz, containing cubes of limonite, pseudomorphous after pyrite, is also commonly found in them.

## Tawng-Peng Granite.

Among the Chaung Magyi rocks great intrusions of granite are found in some places, especially in the main area in Tawng-Peng, and these, according to La Touche,[2] may perhaps belong to the same period as that in which the ejection of the rhyolites took place. These rocks are especially conspicuous in the neighbourhood of Nam Hsan, the capital of the Tawng-Peng State. According to the same author, large dykes of granite also proceed from this granitic expanse towards the north-east, to within

[1] *Rec. Geol. Surv. Ind.* vol. xxxiv, 1906, pp. 154-160.
[2] *Mem. Geol. Surv. Ind.* vol. xxxix, 1913, p. 59.

a few miles of the rhyolitic area of Bawdwin. Intrusions of granite also occur among the Chaung Magyi rocks on the north side of Loi Pan, in Möng Tung State, and along the southern slopes of Loi Ling in South Hsenwi.

The rock is an ordinary granite, consisting of quartz, orthoclase felspar, sometimes microcline, and biotite, and it usually bears evidence of intense crushing. It differs from the granite of the Ruby Mines district in containing no tourmaline.

## Intrusive Rocks in the Northern Shan States.

**Diorite near Hpalam.**—Intrusions of basic rocks are rare in the Northern Shan States. Such intrusions as do occur are confined to the oldest rocks and are of rare occurrence in them. One small dyke was recorded by La Touche in the mica schists to the south of the Ruby Mines, between the villages of Hpalam and Nalaw, thirteen miles east-south-east of Mogok. This rock is a dark greenish diorite with a specific gravity of 2·873, consisting of labradorite and pale green hornblende. The latter forms a minutely crystalline cataclastic groundmass ophitically surrounding the felspar. The only accessory minerals are iron ores and a few very minute needles of apatite. The whole rock is remarkably fresh-looking, but the hornblende may be of secondary origin, in which case the term epidiorite would be more appropriate.

**Olivine-Gabbro.**—The only other locality in which basic dykes older than the Tertiary period have been found is in the neighbourhood of Nam Hsan, near the eastern edge of the granite area, into which they have intruded. The rock is coarse-grained, dense, black, and holocrystalline, with a specific gravity of 3·012 to 3·04. The constituents are olivine in large granules, with a peculiar violet-brown tinge ascribed to the presence of manganese, plagioclase felspar, either a basic variety of andesine or labradorite, and colourless augite, the latter ophitically surrounding the olivine and felspar. A narrow reaction rim is developed surrounding the olivine crystals, wherever they come in contact with the felspars. This rim consists of two zones, the inner very narrow, composed of a colourless minutely granular mineral, while the outer zone,

which is often much broader, consists of a finely fibrous also colourless mineral, which may be tremolite. The felspar possesses a light reddish-brown colour due to the presence of minute inclusions. Magnetite in fairly large quantities and a little biotite are the only accessories present.

Similarly, according to Sahni,[1] granite is intruded in a number of places by basic rocks varying in facies from dolerite and epidiorite to olivine-basalt. Biotite is sometimes present in small quantity. The largest of these intrusions, besides several smaller ones, occupies the extreme south-west corner of the Survey of India, one-inch, Burma sheet, E. 10, and covers an area of several miles.

## Silicified Tuffs, Lagwi Pass, Chinese Frontier.

Volcanic rocks similar to those at Bawdwin were found by Dr. Murray Stuart[2] at the Lagwi pass (25° 48′, 98° 32′), situated on the Burma-China frontier. The writer visited this area twice in 1930 and in 1931. The rocks are dark grey, fine-grained siliceous tuffs, composed of highly angular quartz fragments surrounded by finer material containing much chlorite. The tuff has obviously undergone alteration, chlorite having developed at the expense of the original dust. Tuff of this type, with very little variation, extends north-eastwards throughout the core of the frontier mountain-range for about three and a half miles, to the sharp easterly bend in the frontier where the galena mines are situated. Here the tuff, slightly more silicified, but otherwise exactly similar to that exposed in the Lagwi Pass, is in contact with white crystalline limestone. At the contact of the limestones and the tuff a band of crystalline zoisite occurs, the mineral showing beautifully developed radiating structure. Nothing is precisely known about the age of these rocks, but it appears to the writer from their petrographic similarity and association with galena that they may tentatively be regarded as of the same age as those of Bawdwin. Moreover, their association with the early Palaeozoic rocks, as at Bawdwin, lends some support to this conclusion.

[1] *Rec. Geol. Surv. Ind.* vol. lxv, 1931, pp. 88-89.

[2] *Rec. Geol. Surv. Ind.* vol. liv, 1923, p. 407.

### Southern Shan States.

According to V. P. Sondhi, east of Alechaung (21° 0′, 96° 33′) the Pindaya beds of Ordovician age are interbedded with rhyolite (see p. 159).

### Volcanic and Associated Rocks of the Mergui Archipelago.

Reference has been made above to the igneous rocks found interbedded with the Mergui Series in some of the outer islands of the Mergui Archipelago. Starting from the north, Tavoy Island group consists of quartzites, altered tuffs and quartz-and felspar-porphyry. Felspar-porphyries, with which volcanic tuffs are associated, are also exposed in the south of Iron Island. Along the northern shore of King Island are found numerous sills of porphyritic granite and schistose granite-porphyry. West of King Island is situated Maingay Island where, according to Dr. Heron, a great development of indubitable volcanic agglomerate is to be seen, composed of quartz, felspar and biotite fragments with chips of glass and quartzite, evidently the products of a paroxysmal eruption of a magma corresponding in composition with granite and rhyolite. Both agglomerate and hypabyssal rocks probably belong to the same period of igneous activity, and from these eruptions came the small angular fragments so extensively distributed throughout the Mergui Series. Such fragments of these volcanic and hypabyssal rocks (porphyries) were noticed by the author in the town of Mergui.

The western coast of Elphinstone Island shows a great series of rhyolites and porphyries, and the high conical peaks of this island are composed of volcanic agglomerates, including fragments of pumice and devitrified glass and pieces of various sedimentary rocks. Associated with these are dykes and small bosses of porphyritic microgranite and granites. Effusive rocks extend round the western coast of Elphinstone Island and the small islets off it, and consist of white tuffs full of bombs and lapilli, felspar-porphyries and cellular rhyolites which look almost like pumice. The large islands to the east of Elphinstone consist of the same rocks.

The occurrence of older intrusions near Talubosa in the Mergui district has been described in the preceding chapter.

### LATE CRETACEOUS—EARLY EOCENE IGNEOUS ACTIVITY.

It has been shown above that a belt of peridotitic intrusions of late Cretaceous to early Eocene age, mainly recorded from the eastern limb of the Arakan Yoma, extends from the frontiers of Burma and Assam in the north to the Andaman and Nicobar Islands in the south. It passes on farther south to Java and Sumatra.

**Naga Hills.**—Sir Edwin Pascoe, while working in the Naga Hills, found small pieces of serpentine in the Lanier river, so that it certainly extends through part of that valley : large fragments of serpentine and gabbro were seen in two of the branches of the large tributary of the Tepe immediately south-west of Chimi, so that there must be igneous exposures west of the ridge here. Between Puchim and Karami the serpentine crops out in the form of a line of conical crag-crowned hills with scant vegetation. Serpentinised lherzolite, dark green serpentine, hornblende-, enstatite-olivine-gabbro and a diallage-gabbro have been described from this area.

**Manipur Hills.**—On the eastern flanks of the Arakan range in the Manipur hills, Oldham mapped a band of serpentine stretching for a distance of nearly forty miles with a breadth of about one mile. He found specimens of dark-coloured serpentine and gabbro.

**Upper Chindwin.**—In the valley of the upper Chindwin river "a great many boulders of serpentine occur, which are very similar to the intrusions described by Pascoe near Sarametti." It has since been concluded by H. S. Bion that "there can therefore be no doubt that the belt of intrusive serpentine which occurs along the inner boundary of the so-called Axials of the Arakan Yoma, Manipur and Naga hills extends to the west of the Tertiary basin and crosses the Chindwin river, a few miles above Kyaukse rapids."

**Jade Mines Area.**—In the Jade Mines area of the Kamaing sub-division, Myitkyina district, the writer traced a great elongated mass, apart from several smaller outcrops, of partially

serpentinised peridotites for a distance of over twenty miles in an approximately N.E.–S.W. direction. The more important varieties of the ultrabasic intrusions are altered dunites, mica-, hornblende-, and diallage-peridotites, pyroxenites and amphibolites. Brecciation and serpentinisation are widespread, and several varieties of serpentine such as antigorite, marmolite and a massive dark green mineral occur. These intrusions are very important economically since jadeite, chromite and iron ores are associated with them.

*Serpentines.*—The prevalent type of serpentine is an ordinary, massive, dark green mineral. However, antigorite is by no means uncommon. In places the laminae have been thrown into acute folds, which become visible on weathered surfaces. Under the microscope the typical antigorite structure is visible. Grains of chromite are also to be seen which sometimes show a streaky arrangement. There is no trace left of the original mineral from which antigorite has developed, and it appears essentially to be a product of strong dynamic metamorphism. In rare cases altered greenish hornblende is associated with antigorite. In places, the thin, foliated variety, marmolite, with a pale green colour, is seen. Occasionally, thin lenticles and seams of a finely fibrous mineral, chrysotile with a pale green colour and silky lustre, occur in the ordinary massive variety.

These ultrabasic intrusions are encircled by a complex of crystalline-schists comprising graphite-, glaucophane-, hornblende-, chlorite-, kyanite-, and quartz-schists, together with less altered igneous rocks ranging from diorites and gabbros to pyroxenites and perknites. Epidiorite, which is sometimes spotted with almost circular felspar crystals, and is mainly derived from gabbro, is the predominant type.

The jadeite is intrusive into serpentine, and important outcrops of the former occur at Tawmaw, Meinmaw, Pangmaw, Namshamaw, etc. Dr. Bleeck believed that the jadeite was formed as a result of the metamorphism of an albite-nepheline rock, but the present writer considers that the mineral is an original magmatic segregation product occurring in the form of lenses in the main mass.[1]

[1] *Rec. Geol. Surv. Ind.* vol. lxiii, 1930, p. 41.

On the western bank of the Mali *hka*, between Myitkyina and Putao, Murray Stuart has noted the occurrence of serpentine.

**Minbu and Kyaukpyu Districts.**—The serpentine occurrences of the Minbu and Kyaukpyu districts, with which steatite is associated, occur, according to Sir Henry Hayden, on the western side of the Arakan Yoma. The same author states that " at about one and a half miles west of Shauktaung the ' Chin Shales ' first appear and continue without interruption to Won. About one and a quarter miles west of Won they are well seen in the steep, precipitous sides of the Maukyaung. Here also occur numerous dykes and intrusions of a grey dolerite which is seen in great masses in the ' Chin Shales.' Numerous boulders of dark green serpentine and a somewhat fine-grained gabbro occur in the stream beds. Two and a half miles west of Sunlar are found large quantities of the same serpentine. The rock has been much crushed, and in places strongly resembles the ' Chin Shales.' "

**Prome and Thayetmyo Districts.**—Ramamirtham has visited the serpentine intrusions of the Prome and Thayetmyo districts recently. The rock is mostly of the same nature as that of the Henzada and Bassein districts referred to below. It is intrusive into the Axial Beds in the Thayetmyo district and into Negrais Beds in the Prome district. He states that " the northernmost mass visited so far is also partly intrusive into the Eocene sandstones " and further, that the serpentine has generally a uniform appearance. It is mostly a soft, dark or dull green rock sometimes with fine and glistening veins of chrysolite, and shining bastite pseudomorphs standing out boldly. Ramamirtham found serpentinised saxonites, lherzolites, dunites and picrites.

In the Thayetmyo district, near the village of Thayetchaung, hornblende-dolerite is associated with a long dyke of serpentine, and the former has been metamorphosed to glaucophane- and actinolite-schists. As a result of the intrusions of serpentine the neighbouring carbonaceous shales of the Axial Beds have been converted into graphitic schists.

**Henzada and Bassein Districts.**—The southernmost intrusions of serpentine in Burma, forming the foothills of the eastern

flank of the Arakan Yoma, occur in the Henzada and northern part of the Bassein district and were examined by the author in 1926.[1] The intrusions of serpentine extend over exactly twenty-six miles from north to south and lie within lat. 17° 24′ and 17° 47′ N. and long. 94° 56′ and 95° 3′ E. Twenty-three exposures of massive and schistose serpentine occur along a north-south line, that is along the strike of the Negrais and Nummulitic rocks, with which serpentine is associated.

The serpentine generally possesses a dark green colour, sometimes with blotches or streaks of apple-green tint. Not infrequently the rock is characterised by conspicuous glistening crystals of bastite, and sometimes it appears porphyritic. At times it is traversed by narrow veins of light green chrysotile or whitish steatite. In places the serpentine is schistose at the junction, but elsewhere the whole mass has been foliated and the resultant rock is a soft, soapy schistose variety. Sometimes as a result of meteoric weathering the rock assumes a leek-green colour. It has a pitch-black or reddish colour on a weathered surface. The rock is highly jointed, as a result of which it cannot be used as an ornamental stone.

Petrologically, the serpentines of this area comprise wholly or partially altered peridotites, saxonites, lherzolites and pure dunites. Interesting types like hornblende-eclogite and hornblende-granulite have been described from the area. The formation of these types indicates that the rocks have undergone high temperature metamorphism under conditions of high pressure and differential stress. At times microdiorite occurs at the periphery of the serpentine masses. Saxonite is the predominant rock in the area.

In places the rocks have undergone silicification, as patches of serpentine have been replaced by amorphous silica. In others, veins of chalcedony, especially along the cleavage planes, are seen penetrating the rock in all directions. At times the borders of the minerals have been replaced, while the interior is left unaltered.

**Western Arakan Yoma.**—Although all the above-mentioned occurrences, with the exception of those of the Minbu and Kyaukpyu districts, are confined almost entirely to the eastern

[1] *Journ. Burma Res. Soc.* vol. xv, 1927, pp. 176-199.

part of the Arakan-Naga Hills, yet another exception must be noted. Theobald stated that "within the limits of Pegu serpentine nowhere occurs on the western slopes of the Arakan range; but in the Sandoway district of Arakan it must be largely developed in some parts of the Mai-i river, to judge by the quantity of this rock seen in the bed of the river, above Lyndi."

**Andaman and Nicobar Islands.**—Altered peridotitic rocks cover a large area in North Andaman Island. They occur at Saddle Peak and Saddle Hill, Rutland and Cinque Islands, and in many other places. The chief rock, according to G. H. Tipper, is a dark green serpentine with veins of chrysotile. The serpentine is derived chiefly from olivine, but in part from hornblende. Two other types have been recognised. One is a peridotite with bronzite, olivine and chrome-spinel (picotite). The other is a decomposed diorite, made up of hornblende, secondary chlorite and a mixture of sericite and calcite derived from plagioclase felspar.

**Middle Andaman Island.**—The serpentines and their associated rocks comprise many of the hills and ridges of the central and the eastern parts of the Middle Andaman Island. These include altered basic and ultrabasic intrusions of plutonic type with occasional doleritic dykes, occurring in close association with red and green jaspers, purple porcellanous limestones, hard grey and yellow quartzites, together with occasional outcrops of calcareous gneiss.

The rocks composing these plutonic complexes vary from augite-, enstatite- and bronzite-peridotites, composed almost wholly of pyroxene with olivine, to more felspathic types belonging to the gabbro group. The olivine is often largely altered to serpentine. In these rocks numerous magnetite grains are often included, together with crystals of picotite. In many cases, these rocks have suffered considerably from crushing and shearing, so that most of the primary minerals have been decomposed and largely replaced by serpentine.

*The Jaspers.*—The jaspers occur as red and greenish types sometimes in the vicinity of the serpentines, but also as individual outcrops among the younger sediments of lower Tertiary age. They are often reticulated with thin veins of

white quartz and fracture conchoidally or into very angular fragments. They are quite distinct from the group of younger sedimentaries, and doubtless owe their present indurated character and shattered appearance to the effects of the intrusions and to the subsequent earth-movements which have resulted in the folded character of the rocks of the island. They constitute the northern promontory of Porlob Island, Rosamund Point and the coastal spur just south of Cuthbert Bay; they also crop out in several places on the mainland.

**Java and Sumatra.**—Passing southwards into Java and Sumatra there are intrusions of peridotites and serpentines which are identical with those of the Andaman and Nicobar Islands.

The rock-types represented by these serpentinised peridotites, with a brief synopsis of the environmental geology of the different areas forming the serpentine belt of Burma and the Andaman and the Nicobar Islands, are shown in the following table :

| 1. Orogenic belt. | 2. Area. | 3. Rock types in sequence. | 4. Age. | 5. Emplacement and mode of intrusion. | 6. Environmental Rocks. | |
|---|---|---|---|---|---|---|
| | | | | | A. Surface (younger) | B. Depth (older) |
| Indo-Burmese mountain arc, comprising the Arakan Yoma, the Manipur, the Naga and the Patkai hills and their southward continuation on to the Andaman and Nicobar Group of Islands. This belt will be referred to as No. 1. | The Andaman and Nicobar Archipelagoes—North Andaman Island. | Bronzite-peridotite, serpentines and diorite. | Late Cretaceous. | Saddle Peak, on the eastern end of the island. Both the subaerial and the submarine slopes are steeper on the east than those on the west. (See fig. 20.) | Conglomerates and sandstones of Eocene age—Upper Ypresian or Lower Lutetian age. | Yellow and red jaspers, porcellanous limestones and quartzites of Upper Cretaceous age and older than the serpentines. |
| | Middle Andaman Island. | Plutonic complexes, varying from augite-, enstatite- and bronzite-peridotite composed almost wholly of pyroxene with olivine to more felspathic types belonging to the gabbro group. These outbursts were followed by volcanic eruptions of tuff, ash, breccia, olivine basalt and augite andesite. | Probably of Cretaceous age. Post-late Cretaceous and preceding Eocene. | Mostly in the eastern part of the range, with one intrusion in the centre. | Eocene sedimentaries consisting of sandstones, conglomerates and clays (containing pebbles of the rocks referred to in Col. 3). | (*a*) Jaspers. (*b*) Porcellanous limestones. (*c*) Quartzites. (*d*) Calc-gneiss. |

| 1. Orogenic belt. | 2. Area. | 3. Rock types in sequence. | 4. Age. | 5. Emplacement and mode of intrusion. | 6. Environmental Rocks. | |
|---|---|---|---|---|---|---|
| | | | | | A. Surface (younger) | B. Depth (older) |
| | | These eruptions preceded the deposition of the Eocene sediments or were contemporaneous with their basal stages. | | | | |
| | Nicobar Island. | Serpentines, gabbro and diorites. | Serpentine rocks are on the whole very much like the Andaman exposures. | — | Clays with interbedded conglomerates (with igneous boulders) and sandstones. | |
| Belt No. 1. | Henzada and Bassein districts. | Twenty-three intrusions of massive and schistose serpentine extend over 26 miles from north to south. The rocks vary from wholly or partially altered peridotites, saxonites and lherzolites to pure dunites. Saxonite is, however, the prevalent type with which chromite is associated. In places microdiorite occurs at the periphery | Late Cretaceous to early Eocene. | The serpentines occur as foothills on the eastern flank of the Arakan Yoma. They occur as bosses forming dome-shaped hills. Sometimes they form long ridges. The southernmost intrusion in the Bassein district occurs on perfectly flat ground, mostly occupied by the Plateau gravel on the east. | Negrais rocks and Nummulitic sandstones. | Negrais Series of Cretaceous age. |

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|---|---|---|---|---|---|---|
| | | | | | A. Surface (younger) | B. Depth (older) |
| | | of the serpentine masses. Hornblende granulite and hornblende eclogite also occur in the area. The Nummulitic sandstones associated with the serpentines consist of quartz, felspar and serpentine. The last mineral forms the great bulk of the rock. In addition fragments of volcanic rocks, showing trachytic arrangement of felspar laths. This proves the existence of some pre-Nummulitic volcanic rock in the Arakan Yoma, probably of about the same age as the serpentines. | | | | |

| 1. Orogenic belt. | 2. Area. | 3. Rock types in sequence. | 4. Age. | 5. Emplacement and mode of intrusion. | 6. Environmental Rocks. | |
|---|---|---|---|---|---|---|
| | | | | | A. Surface (younger) | B. Depth (older) |
| Belt No. I. | Myaungmya district. | The volcanic rocks are situated on both sides of the Bassein River. On the east of the river they form a plateau with an average height of about 100 feet and it presents a steep scarp towards the river. The rocks consist of :<br>(2) white and greenish fine tuffs ;<br>(1) coarse - grained greyish tuffs with *Nummulites*.<br>These tuffs enclose purplish or greyish nodules and boulders of olivine trachyte. Specimens of pitchstones also occur in this area. Volcanic ashes of greyish to greyish-black colour occur exclusively in the hills east of Zyatchaung. They form | Eocene. | Eastern foothills of the Arakan Yoma. This area represents the southernmost occurrence of volcanic rocks in Burma situated on the igneous line connected with the Western Hill ranges. | Nummulitic limestones, sandstones and shales. | |

| 1. Orogenic belt. | 2. Area. | 3. Rock types in sequence. | 4. Age. | 5. Emplacement and mode of intrusion. | 6. Environmental Rocks. A. Surface (younger) | 6. Environmental Rocks. B. Depth (older) |
|---|---|---|---|---|---|---|
| | | a line of low hills with an average elevation of 100 feet running in a N.W.-S.E. direction. They are bedded at times on a very fine scale. | | | | |
| Belt No. 1. | Prome district | Saxonites, lherzolites, dunites, and picrites. | Post-Negrais or post-Cretaceous. | Eastern slopes of the Arakan Yoma. | Negrais Series. | |
| | Thayetmyo district. | Besides the types mentioned above for the Prome district, hornblende dolerite is found associated with a long dyke of serpentine near the village of Thayetchaung, and the former has been metamorphosed to glaucophane, and actinolite schists. As a result of the intrusion the neighbouring carbonaceous shales of the Axial Beds have been converted | Post-Axials. | Eastern slopes of the Arakan Yoma. | Axial Series. | |

| 1. Orogenic belt. | 2. Area. | 3. Rock types in sequence. | 4. Age. | 5. Emplacement and mode of intrusion. | 6. Environmental Rocks. | |
|---|---|---|---|---|---|---|
| | | | | | A. Surface (younger) | B. Depth (older) |
| Belt No. 1. | Manipur and Naga Hills. | Dark-coloured serpentine and gabbro. Contemporaneous volcanic ash deposits interstratified with shales occur near Kachao. | Post-Cretaceous and pre-Nummulitic. | The serpentines occur in dykes of varying sizes, the main intrusions forming a band a mile or two in breadth which runs throughout the whole of the district in a general north and south direction. The intrusions are confined to the eastern limit of the hill rocks. | Limestones and coloured shales. | |
| Belt No. 1. | Minbu and Kyaukpyu districts. | Dark green serpentine with a fine-grained green gabbro. Numerous dykes of a grey dolerite also occur. | Eocene—intrusive into limestone with *Nummulites*. | Both on the eastern and western flanks of the Arakan Yoma. | Sandstones are underlain by thick beds of very finely laminated dark shale with occasional carbonaceous bands. These shales contain a thick bed of grey limestone with *Nummulites*, and have been metamorphosed | |

| 1. Orogenic belt. | 2. Area. | 3. Rock types in sequence. | 4. Age. | 5. Emplacement and mode of intrusion. | 6. Environmental Rocks. | |
|---|---|---|---|---|---|---|
| | | | | | A. Surface (younger) | B. Depth (younger) |
| | | | | | by the intrusions of serpentine. Beneath the limestone come (1) a bed of very dark purple schist containing some limestone bands and succeeded by (2) an immense thickness of green and purple shales containing enormous quantities of vein quartz. | |
| Belt No. 1. | Naga Hills of Assam. | Serpentinised lherzolite, dark green serpentine, hornblende-enstatite-olivine gabbro and a diallage gabbro. A volcanic rock with andesitic groundmass is also described from the area. Quartz occurs as thin veins or eye-shaped len- | Upper Cretaceous. | | Disang Series (Cretaceous) consisting of Disang shales, felspathic grits and conglomerates (with pebbles of serpentine and the "Axials"): age uncertain—(Mesozoic). | |

| 1. Orogenic belt. | 2. Area. | 3. Rock types in sequence. | 4. Age. | 5. Emplacement and mode of intrusion. | 6. Environmental Rocks. | |
|---|---|---|---|---|---|---|
| | | | | | A. Surface (younger) | B. Depth (older) |
| | | ticles in the Disang Series (Cretaceous) in the neighbourhood of serpentine outcrops. | | | | |
| | Singpho Hills. | Serpentine blocks were observed by La Touche in the Upper Dehing Valley. | | | | |

### Serpentine Intrusions and their Contact Effects.

The writer, whilst working in the Henzada and Bassein districts, found that round the igneous intrusions there is sometimes a well-marked aureole of metamorphism, in which typical chlorite- and talc-schists are developed which are occasionally highly stained with iron salts, and then present various shades of red and yellow. At other places only induration, hardening and baking of the country rock is to be observed. Theobald[1] remarked: "this difference in metamorphism is due rather to the composition of the invaded rocks than to any other occult cause." The writer studied this phenomenon very carefully in the field, and has arrived at the conclusion that wherever the country rock consisted of shales, the schists were the result of metamorphism. When sandstones formed the country rock, however, there resulted only baking, hardening, induration and crushing. In places the sandstone, as a result of the igneous action, has become hard enough to ring under the hammer. This conclusion was arrived at as a result of the schists grading into the shales and altered sandstones into normal sandstones. Not infrequently, as a result of the metamorphism of black carbonaceous shales, graphite has been formed, and impure graphite-schists are not rare near the contact.

Sir Edwin Pascoe, while describing the serpentines of the Naga Hills, remarked that "in other places the serpentine with its associated chrysotile and chlorite has to a large extent become schistose and is with difficulty distinguishable from the metamorphosed sedimentaries in which it occurs." Oldham, in connection with the serpentines of the Manipur Hills, was struck by the similarity of their effect on the country rock, and quoted Theobald: "In the neighbourhood of some of the large masses of serpentine the sandstones and shales are converted into greenstone and chloritic schists; but the effect varies and in some instances the neighbouring rocks appear almost unaltered." He said "all this is true word for word of the serpentine of Manipur as of that in Pegu."

Henry Hayden, while discussing the geology of the neighbourhood of the serpentines of the Minbu district, said that in

[1] *Mem. Geol. Surv. Ind.* vol. x, 1873, pp. 143-148.

these shales occur at first narrow bands of sandstone and beneath these a thick bed of grey limestone, with *Nummulites* in places; as a rule, however, in this neighbourhood, the limestones have been altered to such an extent by outbursts of a dark green serpentine that the fossils are not recognisable."

Ramamirtham, who investigated the serpentines of the Prome and Thayetmyo districts, states that as a direct result of the serpentine intrusion the limestone of the Negrais and Axial beds has been converted into hard and compact crystalline limestone and sometimes into marble, blocks of which are found in plenty in the river beds draining those areas. The effect on the sandstone is not marked. Beyond the induration, hardening and the local injection of silica, no other effect is noticeable.

### Causes of Serpentinisation.

It has been shown above that the serpentine is associated with saxonites, lherzolites, dunites and other peridotites. It is apparent that apart from the serpentine itself other associated minerals also are undoubtedly the product of hydration. Besides, these rocks have been considerably silicified. Quartz in the form of lenses and veins is found associated with the rocks occurring in the vicinity of serpentine, in almost every area where the latter exists. Injections of chert, boulders of jasper and other siliceous masses are found in the neighbourhood. The writer, as shown in the sequel, also found lodes of iron pyrites associated with the serpentines of the Bassein district. In places black carbonised serpentine occurs, which by the natives was mistaken for coal. It feebly effervesces with acid. It is, therefore, not unlikely that hydrothermal (magmatic) waters containing silica, iron, etc., in solution were responsible for the widespread serpentinisation of the original minerals.

As a result of subsequent metamorphism, mostly dynamic, variolitic, schistose and antigorite-serpentine have been formed.

### The Intrusive Sequence.

1. It has not been found possible in the field to demarcate the zones of the different types of ultrabasic and basic rocks,

but there is little doubt that as a result of differentiation *in situ* of the intrusive body, chromite, saxonite, lherzolite, dunite and other peridotites have been formed. No syenites or granites have been yet found in this region. These ultra-basic rocks really form the first phase of igneous activity in this belt.

2. The second phase is represented by the microdiorite which occurs at the periphery in the form of a ring around some of the masses of altered peridotites.

3. After the above two phases the residue consisted of free silica which injected itself in the form of veins and lenses of quartz into the neighbouring rocks. The author, when describing the serpentines of the Henzada and Bassein districts, wrote: "It is singular that a very great quantity of quartz is associated with these schists, the size of the quartz boulders varying from a few inches to a few feet in diameter. Sometimes quartz is seen occurring in the form of veins."

Sir Edwin Pascoe, describing the Disang Series in the neighbourhood of serpentines, states that passing eastwards metamorphism increases and a transition from shales to hard glossy slates takes place ; these are usually dark blue in colour, weathering to a greenish or greyish white. East of Cheswe-juma thin veins of quartz become more noticeable and reach a thickness of three or four feet east of Chimi : near the junction of the Tepe with the Tuzu and elsewhere quartz is seen in eye-shaped lenticles in the slate. Similarly, farther south in the Minbu district, Hayden found in the neighbourhood of serpentines enormous quantities of vein quartz occurring in the "Chin Shales."

Dr. Stoliczka [1] also noted the association of quartz with the serpentines of the Puga valley in the following words : "What is still remarkable and worthy of notice, are large spheroidal masses of quartz, which in addition to numerous quartz veins occur throughout the serpentine rock." In this connection it is interesting to notice that Sir Thomas Holland [2] remarked in his *Memoir* on the "Geology of the Neighbourhood of Salem, Madras Presidency": "There are many such examples of

[1] *Mem. Geol. Surv. Ind.* vol. v, 1865, pp. 128-129.
[2] *Mem. Geol. Surv. Ind.* vol. xxx, 1901, pp. 133-138.

peridotite in South India largely altered to magnesite, and they are often accompanied by masses of white quartz containing liquid carbonic acid. The association of two such extremes, dunite and quartz, is far too frequent to be fortuitous and it is not unlikely that the two are genetic relations, the quartz representing the siliceous end-product of the eruption which, in the absence of alumina and alkalies, must consolidate as simple quartz instead of forming alumina-alkaline silicates."

4. The fourth phase marked the activity of the hydrothermal waters with iron, silica, etc., in solution which brought about the widespread serpentinisation of these rocks. It was at this time that lenticles of chert, jasper and chalcedony were deposited in the neighbouring rocks.

## Age of the Serpentine Intrusions.

As shown by the author, the serpentines of the Henzada and Bassein districts are as a rule intrusive into the Negrais rocks; but in places they appear to bear the same relations to the lower portion of the Nummulitic Sandstone Series (Eocene), a fact recorded by Dr. Murray Stuart also. It appears that the Nummulitic Sandstones overlap across the Negrais Series, as one proceeds southwards, and the author thinks that igneous activity extended over some period from the late Cretaceous to the early Eocene. It is probable that while some masses of serpentine were already undergoing denudation, others were still to be erupted into the newly deposited Sandstone Series.

Tipper in his memoir made the following remarks about the age of the serpentines of the Andaman Islands: "These rocks have been considered as intrusive into the Tertiary sediments. There is no evidence in support of this conclusion, but a good deal to show that the serpentines are pre-Tertiary. Fragments and pebbles of serpentine often form part of the Eocene conglomerates of the North Andaman Island. The serpentines were therefore undergoing denudation while the Eocene conglomerates were being formed. The igneous rocks must be at least anterior to the sediments of Upper Ypresian or Lower Lutetian age, considering that the great intrusions of serpentines, peridotites, gabbros and diorites in Baluchistan and elsewhere

in India are of Upper Cretaceous age. I think that similar rocks in the Andamans are of the same age. Also associated with the serpentines are rocks which I believe are in part of Lower Cretaceous age and into which the igneous rocks were intrusive."

It is very interesting and noteworthy that Oldham found serpentines similar to those of the Henzada and Bassein districts in the Manipur and Naga hills. This perfect similarity of characters and position of the rocks, on which Oldham laid great emphasis, is most probably due to community of origin. With regard to the date of the outburst of serpentine, Oldham remarked in the following words : "The date of this intrusion is, as I have already said, posterior to that of the rocks to which I have assigned a Triassic age, possibly also to those to which a Cretaceous age has been attributed, and it is worthy of notice as additional evidence, that these rocks in which it is intrusive are not of Nummulitic age ; that in Pegu, the trap is nowhere found intrusive into rocks of undoubtedly Nummulitic age." However, Oldham seems to follow Theobald in this matter, but reference to the latter's map shows that he (Theobald) marked one patch (lat. 19° 1′ N. and long. 94° 58′ E.) just at the junction of the Negrais and Nummulitic Series.

By reading carefully the description given by the late Sir Henry Hayden it appears that serpentines are intrusive into the Eocene rocks with *Nummulites* in the Minbu district also.

Dr. Murray Stuart found serpentine similar to those described by R. D. Oldham and Sir Edwin Pascoe, intrusive into the Disang Series. The age of the Disang Series is not certain, but it is regarded as the equivalent of part of the Negrais rocks of the Arakan Yoma. Murray Stuart wrote : "The youngest rocks that I know of at present that are traversed by serpentine intrusions are the coal-bearing sandstones of Henzada, which I correlated provisionally with the Laki stage."

With regard to the age of the serpentine intrusions of India, reference may be made to the author's paper on the serpentines of the Henzada and Bassein districts and, from the foregoing discussion, it will appear that the conclusion drawn as to the age of the serpentines is not erroneous. It appears

true that the serpentine intrusions are, at least, of late Cretaceous age, but it is noteworthy that the igneous activity extended up to the early Eocene period. The igneous activity manifested itself either at the close of the Mesozoic period or the beginning of the Tertiary period. The argument for the contemporaneity of these different occurrences rests on their significant linear distribution and their remarkable petrographic similarity. Very probably all the serpentines were intruded during one definite phase or period in the geological development of Burma, most probably about the time when the Arakan-Naga hill ranges were first upheaved from the bottom of the sea, and this phase most probably coincided with the first phase of the Himalayan uplift. The most important minerals associated with these deposits are chromite, iron-ores and jadeite, which will be described in detail below.

## Volcanic Activity Contemporaneous with Serpentine Intrusions.

It has been mentioned above that volcanic eruptions occurred contemporaneously with the peridotitic intrusions in several areas in Burma. Beginning from the north we have the volcano of Kawt-ta-Bum in the Hukawng valley, which the writer [1] visited in 1930, and where volcanic material is interbedded with rocks containing unmistakable *Nummulites*.

**Kawt-ta-Bum, Hukawng Valley.**—The elongated dome of the Kawt-ta-Bum, 4,606 feet high, is built of volcanic breccia and forms a conspicuous landmark in the east of the Hukawng valley. From 2,500 feet upwards, after crossing the Hkawngchit *hka* for the second time *en route* to Prayang, breccia blocks alone were observed forming the northern slopes of the hill. Below that height to the salt spring, known as the Hkawngchit Shayit, large hard blocks of breccia are seen continuously. Lower down in the Shayit *hka*, down to the confluence of the Senu with the Singep *hka* and the Kapdup *hka*, and some of its tributaries on the east, blocks of breccia were seen embedded in the lower Tertiaries, showing thereby that it was a contem-

[1] *Rec. Geol. Surv. Ind.* vol. lxv, 1931, pp. 78-79.

poraneous volcanic action, since Nummulitic limestone is interbedded with the conglomerates containing these blocks.

Towards the top, on the northern slopes, where the wiry growth of bamboo sets in above 3,500 feet, fresh rock is rare; occasionally completely weathered red boulders are to be seen. On and towards the top, blocks of fine-grained tuff and consolidated ash were observed. The blocks of breccia, weathering by exfoliation, and small pieces of breccia or lapilli were seen dispersed on the surface. The soil is usually light coloured and clayey.

**Manipur Hills.**—Oldham has described volcanic ash and contemporaneous volcanic deposits near Kachao, which, from their nature and composition, seem to have been derived from the same source as the great trappean intrusions of the neighbourhood.

**Pakokku District.**—According to Dr. Cotter [1] the uppermost Cretaceous was marked in the western hill ranges of Burma by considerable volcanic activity. The beds below the Eocene basal conglomerate appear to be ashy, and there are numerous outcrops of serpentine along this horizon. There is evidence in the Pondaung Series of the Shinmadaung range of volcanic activity contemporaneous with the deposition of these beds of Eocene age.

**Minbu District.**—Henry Hayden [2] found numerous dykes and intrusions of a grey dolerite in the "Chin Shales" in the Minbu district, associated with the serpentines and gabbro of this region.

**Henzada District.**—The author, while studying thin sections of Nummulitic sandstones associated with the serpentines of the Henzada district, found the former to consist of quartz, felspar and serpentine. The last mineral formed the great bulk of the rock. Besides, fragments of volcanic rocks showing trachytic arrangements of felspar laths were found in several slides of these sandstones. This proves the existence of some pre-Nummulitic volcanic rocks in the Arakan Yoma, probably of about the same age as the serpentines.

**Myaungmya and Bassein Districts.**—Farther southwards a

[1] *Journ. Asiatic Soc. Beng.* N.S. vol. xiv, 1918, p. 409.

[2] *Proc. Ind. Sci. Cong.* Calcutta, 1928.

big area, as investigated by the writer, is occupied by volcanic rocks of Eocene age in the Bassein and Myaungmya districts on both sides of the Bassein river. On the east they form a plateau with an average height of about 100 feet presenting a steep scarp towards the river. The rocks can be classified into :

1. White and greenish fine tuffs ;
2. Coarse-grained greyish tuffs with *Nummulites*. These tuffs enclose purplish or greyish nodules and boulders of olivine-trachyte. Specimens of pitchstones also occur in this area. The eruptions were of a very explosive type.

Volcanic ashes of greyish to greyish-black colour were seen to occur exclusively in the hills east of Zyatchaung. They form a line of low hills with an average elevation of 100 feet running in a N.W.–S.E. direction. They are bedded at times on a very fine scale, approaching lamination.

**Middle Andaman Island.**—Gee [1] has recorded the occurrence of pebbles of volcanic rock in the conglomerates of the Eocene rocks of the Middle Andaman Island. The sandstone grains are usually very angular and include fragments of volcanic ash and numerous fragments of angular felspars. Such ashy sandstones are prominent in the conspicuous hill near the Yol-Jig and again in the north of the island in the green sandstones around Bonnington. Similar strata also occur in other parts of the island, grading into beds of volcanic tuff usually of andesitic type. Such definite volcanic ashes appear to occur at the base of the sandstone division. These ashes seem to occupy a position similar to the basal ashy conglomerates in the Pakokku district referred to above.

*Olivine-Basalt.*—More striking, however, is the occurrence of outcrops of definite volcanic rock of intermediate and basic character. In the Bom-lung-ta Creek, a short distance above Sinker, an isolated outcrop of basalt occurs in the mangrove swamp. The rock is an olivine-basalt consisting of numerous lath-shaped labradorite crystals with marked flow structure. The olivine occurs as fairly large crystals partly decomposed into calcite and serpentine. Unaltered augite is also present. These constituents, together with the numerous felspar laths,

[1] *Rec. Geol. Surv. Ind.* vol. lix, 1926, pp. 213-215.

are included in a brown matrix in which magnetite grains are frequent.

*Augite-Andesite.*—Again, in a stream leading down the western slopes of Mount Wood, a large boulder of green vesicular volcanic rock was observed by Mr. E. R. Gee. The rock is a vesicular augite-andesite consisting of large porphyritic crystals of albite, some augite with numerous vesicles filled with secondary green celadonite (?) in the form of spherulites. The matrix is brownish green in colour, composed partly of glass. Near the same locality a purple breccia of angular blocks of andesitic rock outcrops in the stream course.

*Stratigraphical Position of the Volcanic Rocks.*—The question of the stratigraphical age of these rocks is somewhat speculative considering the number and nature of the outcrops. From the fact, however, that these volcanic rocks are frequent as pebbles in the Lower Eocene conglomerates, and, on the other hand, do not exhibit the marked alteration which the older rocks associated with the serpentine series show, it is probable that they represent a phase of volcanic activity following on the primary upheavals of these older serpentine rocks and preceding the deposition of the Eocene sediments.

## Granites.

As suggested above, the granites of the eastern hill ranges, extending from the Mergui district in the south to the Kyaukse district in the north, perhaps represent the complementary phase of the igneous activity responsible for the peridotitic intrusions described above.

**Tavoy District.**—The granites of the Tavoy district have been studied in detail by J. Coggin Brown and A. M. Heron. According to these authors all the major granites of the Tavoy district, which have been divided into six groups based on their geographical distribution, are markedly elongated parallel to the general strike, *i.e.* about N.N.W.–S.S.E.

*Composition.*—The granite varies considerably in grain and texture, but is of very uniform mineralogical composition all over the district, and in fact, wherever observed, as far north as the Yamethin district and south to the farthest extremity

of Burma. It contains abundant quartz, both orthoclase and acid plagioclase, the former frequently as large phenocrysts, with sometimes microcline and micropegmatite. Biotite is usually present, but is replaced by muscovite at the periphery. Hornblende is rare and always occurs in small quantity.

Accessory minerals are remarkably scarce in the granite itself, apart from veins. Iron pyrites is locally common and is probably an original accessory. Sphene and zircon are rare. In the heavy concentrates from stream sands and granite soils near the contacts, magnetite, garnet, zircon and a greenish-white opaque monazite or other thorium-bearing mineral, are found in lesser amount and are probably sparsely distributed in portions of the granite.

*Texture and Structure.*—Generally speaking, the granite may be described as coarse-grained and porphyritic towards the centre of each intrusion, becoming finer and more uniform towards the edges. In a few cases pseudo-foliation has been developed near the contact, caused by slight motion in an almost consolidated magma, the fine crystals being drawn out in lines curving round the larger felspars. The minerals show little effect of dynamic stresses.

Generally the granite is very sparingly jointed, with the result that it forms great curving surfaces of bare rock with only minor inequalities, and none of the fantastic sculpturing, which characterises granite weathering in tropical lands of low rainfall and considerable temperature variations, is seen.

Inclusions of the rocks of the Mergui Series of all shapes and sizes are common in the granite, especially, of course, near the peripheries of intrusions, but they also occur more sparingly in deep-seated portions.

*Veins.*—In the Tavoy district the granite is injected by veins of acid pegmatite, basic pegmatite, quartz, basic rocks and tourmaline pegmatite. The last are later than the granite in time of intrusion and appear to be distinct from it so far as is known up to the present. These are indistinguishable from the quartz-felspar pegmatites belonging to the granite, except in so far as they are of later age and cut across them and quartz veins. The minerals composing them are orthoclase, quartz and tourmaline, the last often in large crystals or

groups of smaller constituents; sometimes both muscovite and tourmaline are absent, and the rock then becomes a quartz-orthoclase aggregate with graphic intergrowth of the two minerals. This type is, in part at least, subsequent to the tourmaline-bearing variety.

*Felspar-Porphyry.*—The granite also sends out a few veins of fine-grained granite and felspar-porphyry; the latter consists of quartz, kaolinised felspar, and in some cases biotite, in a crypto-crystalline and granophyric groundmass. These porphyries pass into normal granites.

**Mergui District.**—Farther south in the Mergui district the granites are again intrusive into the Mergui Series consisting of unfossiliferous argillites and slates, and are exposed in a series of bosses, which have been grouped into three distinct ranges by Sethu Rama Rao.[1]

*Macroscopic Characters.*—Two types of granite have been recognised in the Mergui district: one, a coarse porphyritic granite devoid of tin; the other a biotite-granite, which is tin-bearing. The former is the older of the two. The rock is traversed by a large number of joints, which facilitate weathering and disintegration. In some of the islands, as, for example, the small ones east of Forbes Island, the granite shows foliation with "augen" structure.

*Microscopic Characters.*—In microscopic sections the normal granite shows quartz, orthoclase partly sericitised, microcline, a little plagioclase and biotite. Hornblende, most of which is chloritised, also occurs. Tourmaline and muscovite are the usual accessories present at the peripheries of the bosses, where biotite is scarce. Cassiterite occurs as a constituent of the smaller bosses of granite. From these minerals it will be seen that there are three varieties of granite present in the Mergui district: (1) biotite-granite, (2) hornblende-granite, (3) tourmaline-muscovite-granite. The last is the most promising for tin-ore in the Mergui district.

**Amherst, Thaton and other Districts.**—Outcrops of granite are seen frequently along the coast of the Amherst and Thaton districts and also on the islands which lie just off it. This granite is a normal type containing quartz, orthoclase,

[1] *Mem. Geol. Surv. Ind.* vol. lv, 1930, pp. 35-40.

biotite or hornblende with accessory sphene or epidote. Sometimes it is well jointed and breaks into tabular blocks. But as the sedimentaries are approached, a belt of very characteristic metamorphic rocks appears, consisting of augen gneiss and banded granulite. Within the metamorphic aureole the biotite-granite frequently contains tourmaline and veins of tourmaline and micropegmatoid rock. In the Toungoo and Salween districts there occur two varieties of granite. One is a fine-grained soda-granite consisting of quartz, dominant idiomorphic albite with subsidiary allotriomorphic orthoclase and large well-preserved laths of biotite. The other is a medium-grained potash-granite composed of quartz with dominant orthoclase, perthite, albite, biotite and accessory magnetite. Associated with these two types of granite are veins of quartz and aplite and dykes of dolerite and hornblende-granophyre with pyrites and hæmatite.

**Green Island and the Amherst Coast.**—L. D. Stamp has investigated the igneous complex of Green Island and the Amherst coast. Here granite is intrusive into the black shales (Mergui Series) which have been metamorphosed into mica- and mica-hornblende-schists. In the field a gradual passage from quartz veins, through coarse muscovite-quartz-pegmatites, quartz-felspar rocks and typical lit-par-lit injections of acid rocks approaching granite in composition into schists, to intrusion gneisses and granites, is traced going down the sequence as one proceeds from the east to the west. The granite has obviously been contaminated by absorption of the country-rock. Large xenoliths of biotite-hornblende-schist in various stages of dissolution are seen. An interesting feature is the invariable development of a pale-coloured reaction zone six inches to a foot in width, between the dark, almost black xenolith and the dark mica-granite. This evidence points to an exchange of material between xenoliths and the surrounding magma. The xenoliths have become enriched in iron and magnesia, while the adjacent layers of magma received alkalis and a little lime. The reaction zone is richer in acid plagioclase but poorer in quartz than the normal granite. Thus the free quartz of the granite appears to have combined with soda and lime from the xenoliths.

Petrographically the rocks comprise a continuous series from ordinary biotite-granite through contaminated granites, intrusion gneisses, granite aplites to pegmatites and quartz veins. All the rocks are mylonised and this micro-structure has been explained as induced by earth-movements during the final stages of crystallisation. The contaminated granites are darker in colour owing to the larger content of biotite. They contain large numbers of xenoliths, which range from huge blocks showing the foliation of ordinary mica-schist, through irregular-shaped masses of all sizes, down to small fragments, almost completely assimilated. The xenoliths, besides the usual minerals of granites, contain hornblende, epidote and some apatite.

**Myitkyina District.**—In the north, as reported by the author, granite occurs in the Jade Mines region, Myitkyina district,[1] where it occupies extensive areas. It builds either little groups of thickly forested hills, sometimes rising to 1,500 feet above the surrounding plain, or scattered bosses and hills or knolls of smaller size. The original intrusion must have had the form of a batholith. The granite shows various shades of pink and grey and is generally medium textured. In places it has a slightly foliated or banded appearance. The predominant type is a biotite-potash-granite with the following varieties: (i) biotite-muscovite-granite, (ii) hornblende-granite and micro-granite, (iii) graphic granite, (iv) granophyre, (v) quartz-augite-monzonite, (vi) quartz-biotite-monzonite and (vii) patches of basic xenoliths, dioritic in composition. In the monzonites, quartz occupies only a subordinate position with orthoclase and plagioclase occurring in almost equal proportions. The latter is mainly oligoclase or oligoclase-andesine in places. In some cases augite, and in others biotite, is the only ferro-magnesian mineral present. Sometimes the granite is permeated by veins of graphic granite and quartz. The foliation in the granite is believed to have developed while the molten magma was still in the viscous state. The author concluded that the granite intrusions took place at earliest during the Mesozoic era.

Granite, as observed by the author, also occupies an

[1] *Rec. Geol. Surv. Ind.* vol. lxiv, 1930, pp. 98-99.

extensive area on the north-eastern frontier of Burma in the Myitkyina District.[1] It is first met on the Htaw-gaw road after crossing the Laugyauglaw *hka* and was traced as far north-eastwards as mile "120" on the Hpimaw road. South-eastwards exposures failed only about a mile short of the Lagwi Pass, 8,850 feet above sea-level. It again crops out near the Inspection Bungalow at Hpimaw (26° 0′, 98° 38′) and was traced as far as the Hpimaw Pass, 10,338 feet above the sea. Farther south it was followed as far as three and a half miles south-south-east of Chu-iho, en route to the Fenshinling Pass. It builds very rugged and broken hills, exceeding 12,000 feet in height. Farther southwards it extends on to the Panwa Pass. The rock is a very coarse biotite-granite, which in places has been injected by veins of graphic and aplitic granite, while quartz veins are fairly common.

Unfortunately there is no means of defining the exact age of these granite masses; all that can be said, as in the case of the granites of the Tavoy and Mergui districts, is that they are at earliest post-Permo-Carboniferous in age.

## Hornblende Lamprophyres and Associated Rocks of Mokpalin Quarries, Thaton District.

The author first visited the Mokpalin stone quarries in September, 1926, and was struck by the occurrence of lamprophyres as small dykes of no great magnitude, seldom exceeding a foot or two in thickness. So far as the author is aware no example of a lamprophyre has hitherto been described from Burma.

*Position of the Quarries.*—The Public Works Department quarries known as the Mokpalin stone quarries are situated about three miles east of Mokpalin railway station on the Pegu-Moulmein railway line. There are three quarries, known as Nos. 1, 2 and 3, and the rocks of the quarry 3 are different from those of 1 and 2. Quarries Nos. 1 and 2 are situated on the opposite flanks of the same hill in similar rocks.

The common rock of quarries 1 and 2 is a hornblende-gneiss with veins or dyke-like masses of a black rock which becomes

[1] *Rec. Geol. Surv. Ind.* vol. lxvi, 1932, p. 90.

porphyritic in places. Xenoliths of the former are seen in the latter, but the reverse relations are also to be seen. In places the light- and dark-coloured rocks are highly banded, and the xenoliths of both, as remarked above, are to be seen in one another, showing that there was not a large time-interval between the intrusions of the two. Acid pegmatites, consisting mainly of quartz and felspar, and quartz veins, also occur. The rocks are covered with a thick cap of laterite.[1] They can be classified as follows:

(*e*) Contact rocks, *e.g.* veins of epidote-rock containing a little quartz and felspar.

(*d*) Quartz veins occurring as irregular veins or lenses.

(*c*) Acidic pegmatites and aplite veins.

(*b*) Lamprophyres. The common rock is a hornblende-lamprophyre (camptonite) merging sometimes into a dark quartz-diorite-gneiss.

(*a*) Hornblende-biotite-gneiss, quartz-diorite-gneiss and biotite-granite.

(*a*) *Granites and Gneisses.*—The gneisses described below show greater affinity to diorite (adamellite) in possessing a fairly basic plagioclase (labradorite), and show characters in common with those developed in the Adamello Alps, the Tyrol and elsewhere.

The rock hammered from quarry No. 3 is white in colour with patches of biotite and greenish-black hornblende. The other minerals that can be recognised with a pocket lens are quartz, felspar, zircon and copper pyrites. The specific gravity of the rock is 2·88. Under the microscope the thin section is seen to consist of a granitoid schistose aggregate of biotite, greenish hornblende, orthoclase and plagioclase felspars and quartz. Sphene, zircon and copper pyrites occur sometimes in big crystals. Some magnetite is also present. In most sections sphene has assumed a white colour due to its alteration to leucoxene.

Another specimen of hornblende-biotite-gneiss shows the same megascopic characters, but a white vein, about $\frac{3}{4}$ of an inch thick, is seen traversing it. The vein consists of coarsely crystallised felspar and quartz with a few specks of hornblende

[1] *Journ. Burma Res. Soc.* vol. xvi, 1926, pp. 167-168.

and epidote. The thin section of the gneiss is seen to consist of quartz, felspar, hornblende, with ragged flakes of biotite. The quartz shows strain shadows. Both orthoclase and plagioclase felspars are present, the latter being as basic as labradorite. In some sections secondary twinning is developed. In places, biotite and hornblende occur intergrown. Inclusions of felspar, quartz, sphene and magnetite are also present in the latter. Epidote is also present, and there is enough evidence in the section to show that it has been formed by the interaction of lime-felspar and hornblende, as it is mostly seen at the junction of these two minerals. In places, only an incipient growth of epidote is to be seen. Felspar in such cases is mostly saussuritised. The section is remarkably rich in accessories: sphene, zircon, apatite and magnetite. Apatite is especially abundant, and occurs both in hexagonal and prismatic sections.

The rock of the quarry No. 2 is of grey colour with prismatic shining black hornblende crystals and white felspars. The noticeable point about this rock is that it contains black patches not unlike those occurring in dark lamprophyres described below. These black patches mostly represent basic segregations, unless they are of the nature of xenoliths, but the author is inclined to the former view. The specific gravity of the rock is 2·73. Under the microscope a thin section is seen to consist of phenocrysts of felspar, hornblende and biotite in a trachytic plexus of felspar crystals with idiomorphic hexagonal and squarish outlines. In the groundmass irregular needles of hornblende and magnetite crystals are also interspersed. Felspar, which occurs both as phenocrysts and in the groundmass, shows both simple and lamellar twinning and very well-marked zoning. In some cases it shows ophitic relations with hornblende and mica.

*Granite-Gneiss.*—The rock of the quarry No. 3 is very leucocratic and is devoid of the injections of lamprophyre. It consists of felspar and quartz with black streaks and specks of biotite and hornblende. A thin section is seen to consist of a granular aggregate of quartz and felspar with ragged biotite. Felspar crystals (labradorite) show zoning and lamellar twinning and the quartz shows strain shadows.

(*b*) *Lamprophyres.* The lamprophyres occur as dykes or veins of no great magnitude intrusive into the gneiss. Their thickness varies from a few inches to a few feet.

*Camptonite.*—The typical camptonite is beautiful grey in colour with glistening black elongated crystals of hornblende and occasionally a few crystals of felspar. These phenocrysts are set in a holocrystalline, greyish groundmass of hornblende and felspar. The specific gravity of the rock is 2·73. Under the microscope a thin section is seen to consist of hornblende and felspar, the latter occurring mainly in the groundmass. The crystals of the former mineral measure from a little over 7 mm. downwards, and occur in hexagonal and prismatic sections. In places inclusions of felspar are to be seen. Simple twinning is developed. In a few cases sphene is seen enclosed within hornblende. Sometimes the mineral has altered to calcite, which is seen interpenetrating hornblende or forming a concentric shell round the latter. There are a few phenocrysts of felspar, which show zoning and both simple and lamellar twinning. Porphyritic crystals of felspar were also noticed in the lamprophyres of the North of England, and these phenocrysts of felspar were, according to Harker,[1] genetically connected with the Shap granite. Irregular blebs of original quartz are also present. Original quartz also occurs in the groundmass of lamprophyres of the North of England. The groundmass consists of a plexus of laths of felspar and hornblende with pyrites, zircon, needles of apatite and small specks of magnetite occurring as accessories.

The hornblende-camptonite from quarry No. 2 contains xenoliths of hornblende-biotite-granite-gneiss, proving thereby that the dykes of lamprophyre were intruded into the former. A thin section of the lamprophyre is seen to show phenocrysts of brown hornblende, which are generally of small size, but some of them are remarkably big. Both simple and lamellar twinning is seen, the twinning plane being (100). The interior of some of the hornblende crystals is filled with magnetite. Hornblende phenocrysts with a few of felspar, which are of rounded shape, are set in a fine dark groundmass, which is holo-

[1] Harker, A., "The Lamprophyres of the North of England," *Geol. Mag.* 1892, p. 200.

crystalline and consists of felspar with small brownish or greenish needles of hornblende and grains of magnetite. Both hornblende and felspar crystals show a parallel disposition. Fine needles of apatite are also visible.

The xenoliths of gneiss show a schistose aggregate of biotite, hornblende, labradorite and orthoclase. Magnetite occurs in fairly large quantities and sphene, zircon, apatite and colourless garnet occur as accessories.

Farther south, similar lamprophyres besides other varieties have been described by J. B. Scrivenor[1] from Malaya.

A camptonite is recorded from Pasir Dula, S. Telemong.

(*c*) *Acid Pegmatites and Aplite Veins.*—The gneiss is injected by veins of whitish acid pegmatites and aplites which generally do not exceed a thickness of more than a few inches. The former generally consist of a coarsely crystallised aggregate of felspar and quartz with a few specks of hornblende and epidote. The aplites are of white colour with fine greyish-black streaks, and consist largely of quartz and felspar; the latter includes some microcline. The quartz shows liquid inclusions. A mineral showing pleochroism varying from almost colourless to light yellow with low refractive index appears to be cordierite.

(*d*) *Quartz Veins.* A few quartz veins were observed in quarry No. 1, intrusive into the gneiss, but they are very irregular in form and occur as lenses.

(*e*) *Contact Rock-veins of Epidote-rock.*—The most important contact rocks are veins of epidote-rock which have developed at the contact of the lamprophyric dykes and the gneiss. Sometimes these veins are mere streaks, commonly parallel and not exceeding an inch in thickness. A specimen hammered from quarry No. 2 is light pistaccio-green in colour with patches or xenoliths of the gneiss consisting of quartz, felspar and mica. Under the microscope, a thin section is seen to consist of yellowish-green epidote in which irregular crystals, of varying size, of quartz and felspar occur. The angular nature of these quartz and felspar crystals is very striking, and they do not appear unlike the fragments seen in a coarse tuff. It seems that these fragments were torn by the invading magma from the

[1] *The Geology of Malaya*, Macmillan, 1931, pp. 38-46.

parent mass and included within it. Felspar and hornblende, as seen also in sections described above, were mostly absorbed to form epidote while quartz remained almost unaffected, though in places it appears to have been very finely comminuted and mixed up with epidote. Another specimen of a quartz-epidote-rock shows a little felspar, probably representing the excess left after uniting with hornblende to form epidote.

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# CHAPTER XXIX

## IGNEOUS ACTIVITY (*Continued*)

## VARIATION IN TIME

### POST-EOCENE IGNEOUS ACTIVITY

### I. Mount Loimye.

There is little doubt that the volcanoes of Mount Loimye and the Wuntho region were active during early Tertiary times, but it is very difficult to assign any exact horizon. They most probably were in eruption during a post-Eocene period, but that does not to the author's mind preclude the possibility of their having been active during uppermost-Eocene times until more definite evidence is forthcoming.

Mount Loimye, being the highest point, forms a very conspicuous landmark in the Kachin Hills of the Kamaing subdivision, Myitkyina district. It is a breccia-and-lava dome, 5,124 feet above the sea-level and is 25 feet higher than the celebrated Mount Popa. In the present state of our knowledge it appears to be the second highest volcano in Burma, the first being the little known Taungthalôn in the Upper Chindwin district.

It may be noted that Mount Loimye is situated in an entirely uninhabited region and the Numjan *hka* provides the only means of approach to the western side of this gigantic volcano. The ascent of the volcano can be made along the spur south of the Loimye *hka*. From its confluence with the Numjan *hka* there is impenetrable jungle up to a height of 4,500 feet and a path has to be cut all along. Above this appears a wiry growth of bamboo which is even more difficult to pass than the trackless jungle below.

On the spur, immediately south of the Loimye *hka*, gabbro

is exposed to a height of about 2,000 feet, above which the ground is rather flat and the soil is red with occasional volcanic boulders. From 2,250 feet to a little above 3,000 feet are to be seen lava

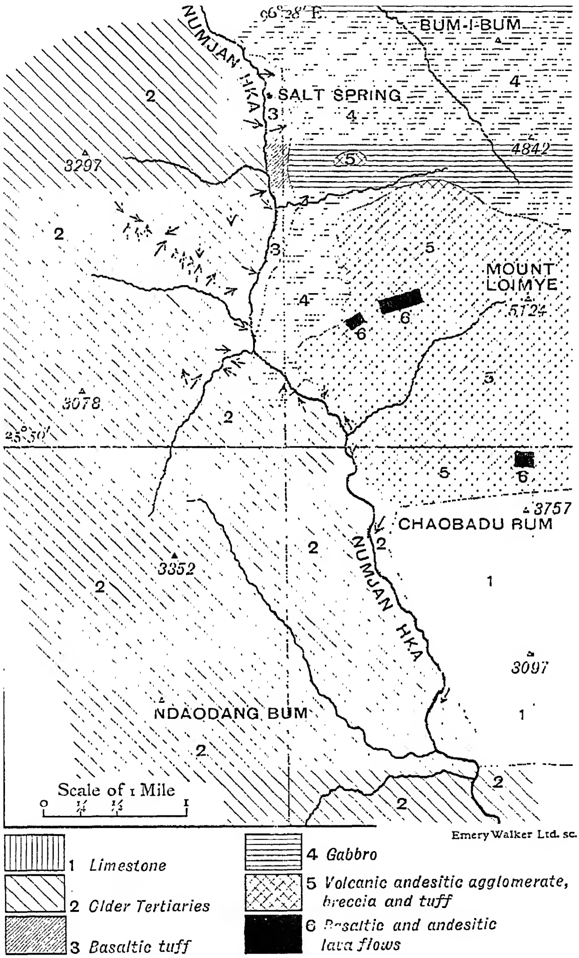


FIG. 22.—Sketch map showing the geology of Mount Loimye, Kamaing subdivision, Myitkyina district.

flows which are overlain roughly to a height of 4,500 feet by volcanic breccia, with lava flows in places where dark purple lava (basalt) with white felspar phenocrysts is predominant.

Above 4,500 feet the dome is composed of volcanic breccia with white bedded ash intercalated in places.

A descent from the top, along the southern spur which connects Mount Loimye with the limestone hill of the Chaobadu Bum, revealed that up to 4,300 feet from the top undoubted breccia occurs, and in places forms big boulders, sometimes about the size of a small hut. From 4,300 to 3,800 feet a whitish felspathic tuff is most common. Below this, to a height of 3,550 feet at least, five distinct flows of lava are recognised in the field as follows:

V. Coarse-grained basalt, almost approaching a dolerite, near the 3,800-ft. level.
IV. Porphyritic enstatite-basalt, at about the 3,750-ft. level.
III. Porphyritic augite-andesite with phenocrysts of labradorite (glassy and altered), between 3,650–3,700 feet, occupying level ground.
II. Doleritic basalt, above the 3,550-ft. contour.
I. Vesicular augite-andesite, at about the 3,550-ft. level.

These readings were taken with an aneroid and must be regarded as approximate only.

In places the sides of the hill are very precipitous. These are sometimes cliffs with a drop of about 1,000 feet.

## History of the Volcano.

The history of the volcano can be divided into four stages:

(1) Black basal tuffs of aqueous origin were interbedded with the Tertiaries and metamorphosed by the intrusion of gabbro.
(2) The initial explosive phase was succeeded by a quiet one when basaltic and andesitic lavas were poured out.
(3) Volcanic breccia with finely bedded, sometimes laminated, consolidated ash or tuffs were formed.
(4) Andesitic and basaltic breccia built up the dome of Mount Loimye. This marks the most explosive and the longest phase.

A complete record of the history of the volcano is preserved on the spur south of the Loimye *hka*, while (2), (3) and (4) are

seen on the southern one leading to the Chaobadu Bum, and only (3) and (4) are observed on the north of Δ 5,124.

### (1) Black Basal Tuffs.

These tuffs are first observed a little south of where the stream issuing from about ¼ mile east of Δ 5,124 joins the Numjan *hka* and extends for about two miles north of the confluence of the Numjan and the Loimye streams. It is undoubtedly an aqueous, bedded deposit, and in places appears to be interbedded with the Tertiaries and has participated in the folding of the area. North of the Loimye *hka* it has been intruded by gabbro. Consequently it has been baked, hardened, bleached and metamorphosed. The rock is greenish-black in colour, with conspicuous crystals of augite. In places it shows nodular weathering.

**Microscopic Characters.**—A thin section is seen to consist of broken crystals of diopside, with prismatic, angular, and subangular outlines, prisms of felspar, showing schiller structure, set in a white base which is isotropic. Augite has mostly altered to brownish or greenish serpentine. Associated with this is similarly coloured palagonite in which concentric or radial gobulites are to be seen. Palagonitisation appears to be due to further alteration of serpentine, a decomposition product of the augite.

### (2) Lava Flows.

So far only the spur immediately south of the Loimye *hka*, and the southern and northern spurs of the volcano, have been examined, and mention has already been made of the occurrence of the lava flows in places. Some of them are described below.

**Vesicular Augite-Andesite.**—The specimen representing the first flow on the southern spur, with steep sides connecting the Chaobadu Bum, is a vesicular dark compact rock in which vesicles have been filled with calcite and palagonite. Under the microscope it is seen to consist of felspar laths with a typical schiller structure set in a dark glass. Augite, which is almost colourless, occurs in idiomorphic sections and in places has altered slightly

to serpentine. Vesicles have been largely filled with calcite, but in places green palagonite in fibrous radiating aggregates (chlorophaeite) is also seen filling them.

**Dolerite or Doleritic Basalt.**—As noted above, dolerite or doleritic basalt marks the third flow on the southern spur of Mount Loimye. Columnar or thick elongated laths of felspar and green augite with ophitic structure are seen to build the rock. The augite is altered to both serpentine and chlorophaeite. The latter is pleochroic and shows a fibrous radiating structure. Magnetite occurs in both regular and irregular patches. Some calcite is also associated and probably replaces the ferro-magnesian minerals.

**Porphyritic Augite-Andesite.**—The rock commencing at 3,650 feet on the spur, south of Δ 5,124, is dark purplish in colour, with felspar phenocrysts and green alteration patches. It marks the third flow. A thin section is seen to consist of large phenocrysts of labradorite and augite set in a hemi-crystalline groundmass composed of felspar laths and dark-brownish glass. Magnetite is also present and has altered to haematite in places. Fine cracks in the rock have been filled with felspathic veins.

**Augite-Basalt.**—A specimen collected from about the 3,500-ft. level, from the spur south of Δ 5,124, is a grey compact rock with vesicles filled with zeolites. Augite has altered to serpentine in places and lacunae of palagonite with concentric banding are also to be seen.

**Porphyritic Basalt.**—The basalt collected from the spur immediately south of the Loimye *hka* just above the 3,000-ft. contour, above the steep ascent between 2,750–3,000 feet, consists of large phenocrysts of andesine felspar and light green diopside, mostly altered to serpentine, set in a hemicrystalline groundmass. The latter is composed of felspar laths, granular augite and magnetite, in dark-greenish glass which appears greenish white by reflected light. Phenocrysts of felspar contain inclusions of altered augite, and in places this simulates schiller structure. The rock appears too basic for an andesite and is in all probability a basalt, though the phenocrysts are rather of acidic character.

### (3) Bedded Consolidated Ash or Tuffs.

As stated above, consolidated ash or tuff is interbedded with breccia, described in the sequel, mostly towards its base. They are finely bedded, in places laminated, proving thereby that they are an aqueous deposit. Some of the types are described below.

**Bedded Ash.**—The rock collected from a little above 4,500 feet on the spur south of the Loimye *hka*, just where the wiry bamboo growth begins, is very fine-textured and shows light grey, purple and greenish bands. Under the microscope it shows small laths of felspar, very tiny angular chips of the same, with small broken fragments of augite set in a volcanic dust, appearing whitish by reflected light with iron-oxide (magnetite and haematite). But the most interesting features are circular and elliptical sections of calcite which probably represent some minute fossil organisms. They may be detached chambers of *Globigerina*. If so, this would denote submarine volcanic eruptions when these deposits were laid down. In places the volcanic matter, felspar and other mineral fragments predominate, while in others calcite forms the greater bulk of the rock.

**Volcanic Ash.**—The specimen taken from 4,600 feet on the northern slopes of Mount Loimye is a dark green bedded and consolidated fine-grained tuff. It is composed of very small angular fragments and microlites of both orthoclase and plagioclase felspars, augite, green palagonite, glass and iron oxides.

**Palagonite Tuff.**—The specimen from about 3,775 feet from the southern spur of Mount Loimye is a dark rock weathering to a pale colour. Under the microscope it is seen to consist of aggregates of small fragments of andesitic lava, felspar, augite, with small circular or elliptical grains of green palagonite with radiating structure. Mostly the last mineral is isotropic, but in places it is birefringent. Small brownish fragments of pumice are quite common.

**Felspathic Tuff.**—The rock from about the 4,000-ft. level from the southern spur of Mount Loimye *en route* to the Chaobadu Bum is a pale grey-coloured felspathic tuff in which crystals of felspar with augite, sometimes angular in outline, are embedded in greenish volcanic dust.

### (4) Volcanic Breccia.

The dome of Mount Loimye is built of coarse greenish-black volcanic breccia in which small blocks or lapilli of andesitic and basaltic lava are sometimes enclosed. This deposit must have a thickness of at least 1,500 feet.

**Andesitic Breccia.**—The specimen hammered from near Δ 5,124 consists of dark-coloured angular or subangular lapilli mottled red on account of haematite.

The thin section shows fragments of andesitic lava sometimes with those of basalt consolidated together. Lapilli of almost all the flows described above, varying in size from that of a coarse sand grain to that of a walnut, are seen to compose this rock. Often the groundmass has been replaced by iron oxides. Phenocrysts of felspar are to be seen in the lapilli, but sometimes they have been partly replaced by iron ores. Light-green augite is mostly altered to serpentine and palagonite. The former makes up a considerable proportion of the rock. The vesicles are sometimes filled with zeolites. The fantastic outlines of the lapilli show that they cannot have been formed by the disruption of a compact lava, but their forms and texture prove that they are true volcanic ejectamenta.

## II. Wuntho Region.

Passing southwards the igneous area which forms part of the Wuntho sub-division in the Katha district is reached. This is one of the biggest igneous regions in Burma, and its boundaries are marked roughly by the Irrawaddy on the east and the Mu on the west. In the area a group of extinct volcanoes form conical hills, domes or huge piles of lava with craters, or ridges, etc. Shinmetaung, a slightly elongated breccia-dome in the neighbourhood of Wuntho, forms a conspicuous landmark rising abruptly from the plains. In the volcano of Minletaung, about four miles west of Wuntho, one of the sides of the crater has been blown away, leaving a horse-shoe shaped hill. The central portion of the region is formed of granitic (granodiorite) rocks, while the surrounding region is made up of volcanic breccia and conglomerate, ash-beds, tuffs, with flows of basalt, breccia being the predominant rock. The

eruptions, as seen in the neighbourhood of Wuntho, were subaqueous, for the oldest volcanic rocks are well stratified beds which show an average dip of 30°. Towards the north of the Upper Chindwin district is the highest volcano in Burma, Taungthalôn, which has not hitherto been explored.

### PLIOCENE CONTEMPORANEOUS IGNEOUS ACTIVITY.

The Pliocene period constitutes the next important orogenic phase. During this period basic volcanic rocks were interbedded with the Irrawaddians at several localities in the Shwebo and other districts of Burma.

#### 1. Lavas of Shwebo District.

The occurrence of lava flows in the south-western corner (Burma Survey Sheet 84M/3) has been mentioned above.

According to L. A. N. Iyer [1] they are fine to medium grained rocks of a dark brown colour, hemicrystalline in character, with porphyritic crystals of plagioclase felspar and a little pyroxene in the groundmass. The phenocrysts vary in size and composition and exhibit corrosion, marginal resorption and zoning. The groundmass varies in the amount of glass present and in the quantities of felspar microlites. The latter are less basic than the phenocrysts. Devitrification of the glass sometimes gives rise to chloritic and brownish products, while the pyroxenes alter to hornblende and chlorite ; chlorite- and silica-filled vesicles also occur.

A few other outcrops [2] of a highly decomposed amygdaloidal basalt have also been found interbedded with the Irrawaddian Series in the same district.

#### 2. The Older Lava of Kabwet Area, Shwebo District.

One of the most interesting and remarkable rocks in the Kabwet area is the lava which occurs interbedded with the Irrawaddian rocks. The outcrop has been traced continuously for over three miles from the Irrawaddy to the Letkokpin *chaung*. The anticlinal axis through Nattaung, Δ 734 hill and

[1] *Rec. Geol. Surv. Ind.*, vol. lxv, 1931, p. 95.

[2] *Rec. Geol. Surv. Ind.*, vol. lxiii, 1930, p. 103.

Letkokpin, is followed by a parallel synclinal axis to the east, passing through Kabwet.[1]

Whatever may have been the original nature of the lava its present features are remarkable. The dip slope, with its dark red colour and irregular surface, resembles laterite outcrops. For a detailed account of its physical characters reference may be made to the original description.[2]

A feature of great interest is the occurrence of "pillow structure" (see Plate XXIII, Fig. 1), each pillow or rounded mass being made up of concentric layers of grey and brown lava. As explained below, this structure may be primary or secondary, and induced by the action of percolating waters. However, it is by no means developed throughout the rock.

Although the best exposures of this lava are along the main outcrop it is evident that the dip flattens out eastwards and that the lava underlies much of the country north of Kabwet village. Small inliers are exposed where the covering Irrawaddian rocks have been removed by denudation. Pebbles of the lava have been found in the overlying sands, and there is thus no doubt that the lava was erupted before the deposition of the overlying sediments. Unfortunately it is too decomposed for its exact nature to be determined.

Farther south in the Shinmadaung range there are rhyolite-conglomerate and breccias which again appear to represent a period of specialised activity during the deposition of the basal Irrawaddian rocks. In the East Monywa Hills one occurrence at least, at Milestone 26 on the Budalin-Ye-u Road, shows a bed of ash interstratified with sands of Irrawaddian age, indicating that volcanic activity was extant during Pliocene times in the Lower Chindwin region. Similar testimony, as shown in the sequel, is forthcoming from the Mount Popa region in the Myingyan district.

## LATE PLIOCENE AND PLEISTOCENE IGNEOUS ACTIVITY.

In Burma the later stages of the Pliocene and the whole of Pleistocene period were very important as regards manifestations of igneous activity which was certainly rife at nine

[1] *Rec. Geol. Surv. Ind.*, vol. lxv, 1931, p. 92.

[2] *Trans. Min. Geol. Inst. Ind.*, vol. xxi, 1927, pp. 98-125.

centres at least, excluding the Têng-Yüeh area in Yunnan. During these eruptions voluminous floods of lava and ashes were poured forth, and the periods of igneous activity were marked by intervals of quiescence and by repeated renewals of volcanic energy.

The different centres comprise those of the Jade Mines area, Myitkyina district, the Lower Chindwin region, Shinmadaung, Mount Popa area, Kabwet area, Shwebo and Mandalay districts, Thaton district, Loi Han Hun volcano in the Northern Shan States and Medaw Island in the Mergui Archipelago. The dolerites of the Pegu Yoma were intruded most probably at about the same time. Some of the old volcanoes in the neighbourhood of Têng-Yüeh in Yunnan and those of Barren Island and Narcondam were also active simultaneously. At some of the centres groups of volcanoes are to be seen at the present day, *e.g.*, in the Lower Chindwin region alone there are seven to eight craters, besides several flows of lava, ash-beds, etc. In the Mount Popa area there are excellent records to show that several volcanoes erupted at different times during this period, and their vestiges are scattered over an area of about 500 square miles.

### 1. Jade Mines Area.

The volcanic rocks of the Jade Mines area can be classified as follows :

(*a*) The Mabaw siliceous agglomerate.
(*b*) Andesite and basalt outcrops in the neighbourhood of Namyong (25° 40′, 96° 26′).

#### (*a*) The Mabaw Siliceous Agglomerate.

The siliceous agglomerate outcrops near the Sanhka village, situated north of the stream of the same name, and continues in a north-easterly direction for about three miles. Since this formation is well developed near Mabaw village (marked Lama on the map—25° 42′ 22″, 96° 21′ 15″), it has been designated the Mabaw Siliceous Agglomerate to distinguish it from other deposits of siliceous breccia-blocks only, occurring so largely in

the area. As shown above (p. 298) the agglomerate contains much serpentine in blocks and lapilli.

Occasionally blocks having a lateritised appearance, and including xenoliths or small boulders of other rocks, are visible. In places, by further concentration, the ferruginous material has been converted into iron ore, lateritic in appearance. Water-worn boulders of serpentine measuring over two feet in diameter, quartz schists, etc., are also embedded in the agglomerate. The bedding is mostly horizontal; in places, however, low south-easterly dips, never exceeding 10°, are to be seen.

The age of the rock has been discussed above (p. 299), and as further evidence of its late-Tertiary age it may be noted that boulders of rhyolite and rhyolite breccia are quite common and rest on the peridotites and serpentine, crystalline schists, the Uru Boulder Conglomerate, etc. The localities where these boulders are found in quantity are given in *Rec. Geol. Surv. Ind.*, vol. lxii, 1929, p. 113.

**Petrology.**—The size of the blocks in the siliceous breccia varies from less than a foot to five or six feet in diameter. The rock has generally a pinkish, reddish or brownish porcellanous appearance. It is not infrequently vesicular. The vesicles, which are sometimes about an inch in diameter, may be original, but they appear to be mainly the result of weathering and ultimate removal of the clastic material, mostly serpentine.

The rock has undoubtedly undergone considerable silicification, since the vesicles are lined with crypto-crystalline silica; moreover, a typical network of siliceous veins often traverses the boulders. Sometimes fine botryoidal incrustations of chalcedony occur.

Under the microscope a thin section is seen to consist of angular fragments of rhyolite with irregular outlines, and of serpentine set in a very fine mosaic of quartz and felspar. The fragments of rhyolite, some of which are quite clear and colourless while others are stained with oxide, have almost the same mineralogical composition as the matrix. Serpentine is almost entirely altered to ferruginous material and is mostly silicified. Almost the whole slide is stained pale yellow with limonite, while grains of haematite and magnetite are also present.

Sometimes lapilli of fibrous serpentine, varying in size from an inch downward, and mostly changed to soft white earth with a soapy feel, are embedded in soft yellow or yellowish-brown paste.

### (*b*) Andesites.

There are several outcrops of andesites and basalts in the neighbourhood of Namyong (25° 40′ 31″, 96° 26′ 17″).

**Andesites.**—The biggest outcrop of typical hornblende-andesite, with augite crystals in some sections, is that of the Janmai Bum, " 1668 " hill (92/C/6). The rock is light grey in colour speckled with glistening black crystals of hornblende.

Two other very small outcrops of hornblende-andesite occur on the path from Namyong to the Tambo *hka*. The first is about a mile N.N.E. and the second a little over 1½ miles N.N.E. of Ngan Gahtawng (95° 41′, 96° 26′).

A sample of hornblende-andesite from the latter locality on analysis yielded the following results : [1]

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ - - | 55·37 | 0·923 | Quartz - - | 7·86 |
| $Al_2O_3$ - - | 16·90 | 0·166 | Orthoclase - | 13·34 |
| $Fe_2O_3$ - - | 5·28 | 0·033 | Albite - - | 30·39 |
| FeO - - | 1·65 | 0·024 | Anorthite - - | 23·35 |
| MgO - - | 4·61 | 0·115 | Diopside— | |
| CaO - - | 5·93 | 0·105 | $CaO.SiO_2$ - | 1·86 |
| $Na_2O$ - - | 3·58 | 0·058 | $MgO.SiO_2$ - | 1·60 |
| $K_2O$ - - | 2·34 | 0·024 | | |
| $H_2O + 110°$ C. - | 1·85 | 0·103 | Enstatite - - | 9·90 |
| $H_2O - 110°$ C. - | 0·92 | 0·051 | Magnetite - - | 4·64 |
| | | | Haematite - - | 2·08 |
| $CO_2$ - - | Traces | — | | |
| $TiO_2$ - - | 0·40 | 0·005 | Ilmenite - - | 0·76 |
| $P_2O_5$ - - | 0·33 | 0·002 | Apatite - - | 0·67 |
| MnO - - | 0·09 | 0·001 | | |
| BaO - - | 0·21 | 0·001 | | 96·45 |
| SrO - - | 0·07 | 0·001 | Water - - | 2·77 |
| Total - | 99·53 | | Total | 99·22 |

Another small outcrop of andesitic rock occurs about a quarter-mile south of Namyong. It is a bluish-grey rock with

[1] Analysis by Dr. A. W. Groves.

dull black crystals which under the microscope prove to be pseudomorphs after hornblende. Pale yellow patches generally surrounding the altered hornblende crystals are present; this bleaching is probably due to the same agencies which brought about the destruction of the hornblende. In addition to the pseudomorphs after hornblende are some pale-green augites set in a trachytic groundmass of felspar laths with grains of iron ore and glass. The pseudomorphs after hornblende are composed of granular iron ore, groundmass, a little enstatite (?) and chalcedonic silica. Felspar too appears to have undergone silicification.

**Hornblende-augite-andesite.**—Andesite again crops out about $1\frac{1}{2}$ furlongs south of Nsengahtawng (25° 40′, 96° 26′) on the new path to the Namting-Lonkin road which joins the latter near the 28th mile. The solid rock is well exposed in a small stream and the maximum extension of the outcrop is not more than a quarter of a mile.

The rock hammered from about three-tenths of a mile S.W. of Nsengahtawng, from the small stream, is purplish in colour, with phenocrysts of dull green hornblende and augite with vesicles in places. The specific gravity is 2·74. A thin section shows a trachytic arrangement of andesine felspar laths with phenocrysts of pale-green augite and pseudomorphs after hornblende. The last mineral can only be recognised by the shape of the pseudomorphs that now consist of magnetite, felspar and glass. This almost complete destruction of hornblende was also noticed in the case of the Mount Popa [1] and the Lower Chindwin lavas. In thin sections of other specimens, however, some unaltered hornblende is seen. Some pseudomorphs are partly filled with enstatite, showing that the hornblende crystallised earlier than the latter. Augite occurs in octagonal prismatic or circular sections as well as in big clusters.

### (c) Hornblende-trachyandesite.

Andesite is exposed in a very small stream issuing near the old road from Namyong to Lonkin, about half a mile N.N.W.

[1] *Trans. Min. Geol. Inst. Ind.*, vol. xxi, 1927, pp. 277-278.

of the 26th mile marked on the Kamaing-Tawmaw mule track. The specimen collected from about one mile 5° west of south of Nsengahtawng on the old path to Lonkin, in the small stream west of the S.S.W. bend of the path, is a pale grey rock with phenocrysts of dark glistening hornblende and white felspar. When observed minutely it shows fluxion structure. The specific gravity is 2·46.

Under the microscope a thin section consists of very elongated or hexagonal sections of brown hornblende, with prismatic, square or hexagonal sections of felspar set in a hemicrystalline groundmass composed of felspar, colourless glass and magnetite. Some of the felspar sections are untwinned while others show simple twinning. The hornblende is partially destroyed and shows reaction rims. Some tiny flakes of sericite are also present. The rock appears to be intermediate in character between a trachyte and an andesite and may justly be named hornblende-trachyandesite.

Its chemical and normative compositions are tabulated below : [1]

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ | 62·00 | 1·033 | Quartz | 17·64 |
| $Al_2O_3$ | 18·80 | 0·184 | Orthoclase | 13·34 |
| $Fe_2O_3$ | 2·96 | 0·018 | Albite | 36·15 |
| FeO | 1·04 | 0·014 | Anorthite | 21·68 |
| MgO | 1·00 | 0·025 | Corundum | 1·33 |
| CaO | 4·71 | 0·084 | Enstatite | 2·50 |
| $Na_2O$ | 4·27 | 0·069 | Magnetite | 2·55 |
| $K_2O$ | 2·31 | 0·024 | Haematite | 1·12 |
| $H_2O+$ | 1·41 | 0·078 | Ilmenite | 0·76 |
| $H_2O-$ | 0·72 | 0·039 | Apatite | 0·67 |
| | | | | 97·74 |
| $CO_2$ | 0·01 | — | Water | 2·13 |
| $TiO_2$ | 0·41 | 0·005 | | |
| $P_2O_5$ | 0·34 | 0·002 | Total | 99·87 |
| MnO | 0·15 | 0·002 | | |
| BaO | 0·07 | — | | |
| Total | 100·20 | | | |

[1] Analysis by T. Marrack, A.R.S.M., M.Sc.

## Basalts.

Three outcrops of basalt occur in the neighbourhood of Namyong (25° 40′ 31″, 96° 26′ 17″).

**Picrite-basalt.**—A very dark compact basalt with phenocrysts of olivine and augite occurs about a quarter of a mile east of Namyong on the old road to Nanyaseik. The specific gravity is 2·96. Under the microscope a thin section is seen to consist of phenocrysts of pyroxenes and colourless clear olivine. The former includes both colourless diopside and green malacolite. The latter occurs in individual prismatic and octagonal sections as well as in clusters showing glomeroporphyritic structure. Some of the sections show well-marked zoning and occasionally hour-glass structure. The olivine is quite fresh. The fine groundmass consists of small laths of labradorite and prismatic, octagonal and granular sections of augite with magnetite.

The rock in question is similar to, if not identical with, the rock which Bleeck designated picrite-porphyry. It, however, bears a very striking resemblance to that described from the Lower Chindwin region as picrite-basalt, and it is also similar to the picrite-basalts described by Holmes from Mozambique, except that the colour of the augite in this case is green.

**Olivine-basalt.**—About a mile south of Namyong the upper portion of " 1371 " hill is built of basalt. The thickness of the lava must be rather small, as the Tertiaries are visible beneath it on the new road to Namting (25° 38′ 45″, 96° 27′ 29″). It may be added that in the watercourses the blocks of lava have a greater extension than elsewhere. It is the largest outcrop of basalt in the neighbourhood.

It is a grey compact olivine-basalt, and under the microscope shows phenocrysts of malacolite, diopside and fresh olivine set in aggregates of lath-shaped felspar with prismatic, octagonal and subangular grains of augite with magnetite. In places felspar builds small phenocrysts which generally lack twinning and show zoning. Small flakes of biotite are also present. The specific gravity is 2·907.

## 2. Igneous Occurrences of the Lower Chindwin Region.

The igneous occurrences described below occur on both banks of the River Chindwin in an area roughly between lat. 21° 31′ and 22° 30′ North and long. 94° 45′ and 95° 30′ East. R. D. Oldham was the first to give a complete account of the explosive craters of this region. Later on, the greater part of this area, roughly 4,000 square miles, was surveyed geologically by Messrs. Pinfold and A. E. Day (see Fig. 23). The central part of the area, both to the east and west of Monywa, was mapped independently by L. D. Stamp in the cold season of 1921-22. The igneous rocks have been examined in the laboratory of the Department of Geology of University College, University of Rangoon, by L. Dudley Stamp and the present writer. The results of the field-work by Messrs. Pinfold and Day and the laboratory work by Dr. Stamp and the author were published in the *Transactions of the Mining and Geological Institute of India*, vol. xxi, 1927, pp. 145-225. Lately Professor Conrad Burri and Herr Hans Huber [1] have published a description of the petrology of some of the rocks from this region.

The igneous rocks form a well-defined series, with certain characteristics which indicate that they belong to the Pacific suite. The volcanic rocks range from rhyolites, in which secondary changes are most marked, through andesites to basalts, among which the most characteristic and interesting members are very basic olivine-basalts (picrite-basalts) approaching basanites but apparently without felspathoids. The hypabyssal rocks include both acid and intermediate types. Some of the basic basalts as well as many of the acid ones should perhaps be classed rather as hypabyssal rocks, occurring, as they do, as plugs or necks. Some of the hypabyssal rocks are coarse-grained and might be classed as plutonic rocks, but it is the ejected blocks from the explosion craters which afford the most interesting examples of plutonic development—more especially a remarkable series of ultrabasic types.

Perhaps the most characteristic rocks of the whole series are the picrite-basalts, and so it will be convenient to arrange the

[1] *Schweiz. Min. Petr. Mitt.*, Band xii, 1932, pp. 286-344.

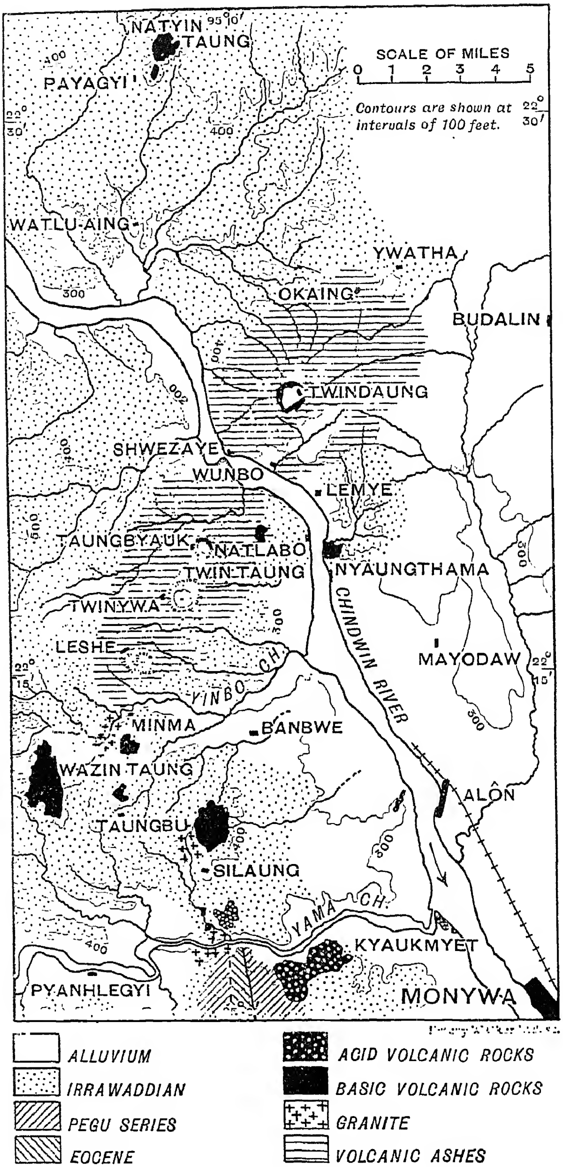


FIG. 23.—Showing the explosion craters of the Lower Chindwin and the geology of the neighbourhood. (*After E. S. Pinfold and A. E. Day.*)

descriptions, starting with the basic types and passing to the intermediate and acid types.

The following rocks are present in the collections :

*Volcanic Rocks.*

I. Picrite-basalts—(*a*) Kyaukka Daung, Hill 779, Natyindaung, North.
(*b*) Thazi Hill.

II. Olivine-basalts—(*a*) Hill 800 and Ye-u Road.
(*b*) Taungbyauk No. 2.
(*c*) Okpo Hill.
(*d*) Natyindaung, South.
(*e*) Twindaung crater.

III. Other basalts— (*f*) Hypersthene-basalt—Okpo.
(*g*) Tachylyte—Okpo.
(*h*) Nepheline-tachylyte—Okpo.

IV. Andesites—(*a*) Pyroxene-andesites in which monoclinic pyroxene is the predominant femic constituent. Hornblende and biotite occur as accessories and olivine is absent. These rocks, together with (*b*), (*c*) and (*d*) below, have been collected from opposite Shwezaye, Taungbyauk and Twindaung craters.

(*b*) Olivine-pyroxene-andesites.

(*c*) Pyroxene-hornblende-andesites. In these rocks there is much brown hornblende.

(*d*) Pyroxene-biotite-andesites. These rocks contain much biotite.

(*e*) Hypersthene-andesite—Yinmabin Road.

(*f*) Acid andesite—Shinmadaung.

V. Rhyolites—(*a*) Rhyolites (devitrified)—West Monywa Hills.
(*b*) Rhyolite (flow breccia)—Kyaukka Daung.

*Hypabyssal Rocks (including altered rocks).*

I. Basic—(*a*) Dolerite—Wunbo.
(*b*) Epidorite and amphibolite—Myayeik and Salingyi.

II. Acid— (*a*) Quartz-porphyry—Hill 1055.
(*b*) Muscovite-porphyry—Hill 994.
(*c*) Hornblende-granite-porphyry—Silaung.

*Plutonic Rocks.*

I. Ultrabasic—(*a*) Peridotites—Twindaung.
(*b*) Perknites—Twindaung.

II. Basic-Intermediate—(*a*) Augite-diorite—Salingyi.
(*b*) Diorite—Salingyi.
(*c*) Quartz-diorite—Twindaung.

*Pyroclastic Rocks.*

Ashes and Tuffs—Twindaung Leshe, Bambwe, Hill 994, 779, 800, Okpo.

*Metamorphic Rocks.*

(*a*) Biotite-gneiss—Twindaung.
(*b*) Hornblende-schist—Twindaung.
(*c*) Quartzite—Kyaukka Daung.

### Different Forms of Igneous Manifestation.

The manifestations of igneous activity in the region assume a number of different forms :

1. Volcanic craters accompanied by deposits of ash, either with or without lava flows.
2. Isolated ash deposits.
3. Lava flows without evidence of a volcanic neck.
4. Intrusive or extrusive masses of the nature of volcanic necks.
5. Intrusions of holocrystalline hypabyssal rocks.

It will, however, be most convenient to consider the volcanic rocks in a series of geographical groups :

(*a*) The explosive craters occurring on both banks of the Chindwin River around the village of Shwezaye.
(*b*) The volcanic occurrences on the west bank of the Chindwin River southwards to Shinmadaung.
(*c*) The volcanic occurrences of the East Monywa Hill Belt.
(*d*) The Natyindaung mass.

### (*a*) The Explosive Craters occurring on both banks of the Chindwin River around the village of Shwezaye.

There exist to-day seven or eight craters in all, which occur roughly in a straight line on both banks of the Chindwin River about the village of Shwezaye (see Fig. 23). The line joining these craters bears in a direction of North 33° East, running somewhat obliquely to the normal tectonic direction of the region.

The distance between the most northerly and southerly craters, Ywatha and Leshe respectively, is about 13 miles.

The country which surrounds these craters on all sides is open plain land floored both by alluvium and quartz-pebble-bearing sands of Irrawaddian age. To the south of Leshe there are isolated plateau-like elevations representing sheets of lava, and still farther south, opposite Monywa, are conical-shaped hills composed of rhyolites and other acid igneous rocks.

**Ywatha.**—This crater is situated some $6\frac{1}{2}$ miles north-east of the Chindwin at Shwezaye. All that remains is a circular depression, broad and shallow, sunk in soft sands of uppermost-Irrawaddian age. In diameter the depression, from rim to rim, measures about half a mile, and is very shallow when compared with its width, averaging only about 150 feet in depth. The bottom is flat and sandy and now partially under cultivation. There is no drainage outlet, however, the rim remaining intact with precipitous inner slopes.

There is a thin coating of ash on the surface of the western rim, but apart from this and the presence of sporadic blocks of lava of basaltic type strewn about the floor and on the outer flanks, subaerial denudation has done its best to remove all traces of the volcanic origin of the crater.

**Twindaung.**—This crater lies on the east bank of the Chindwin River about 2 miles north-east from Shwezaye. Although this is not the largest crater in actual diameter it is the deepest and most perfectly preserved on account of having a partial rim of basalt on its three sides.

Viewed at a distance from the east the flat cone of the crater appears as a broad plateau-like elevation, and there is nothing in the topographic outline to suggest the existence of a volcanic vent.

Approaching from Budalin we find the first indications of the

proximity of volcanic activity at the village of Kyauko, where, in a stream bed to the west of the village, are horizontal deposits of coarse volcanic ash and lapilli and fragments of lava, with a few quartz pebbles, between layers of a fine mud-coloured ash. Although this locality is nearer to the Ywatha crater, which is only 2 miles distant, than to Twindaung, yet the ashes have undoubtedly been ejected from Twindaung, as there is no mistaking the characteristic lava which forms part of the wall of this crater. In addition to the fragments of lava there are also individual crystals of black glistening hornblende and brown mica, mixed up with the lapilli and ash, evidently comprising part of the ejectmenta from this volcano.

The line running through Kyauki village marks roughly the outer limit of ejected material in this direction, a distance of 4½ miles from the crater's edge.

Approaching the crater from the east and north one passes over a volcanic plain built up of deposits of ash.

The inner slopes of the crater are everywhere precipitous. Lying some three to four hundred feet below are the still dark waters of the crater lake which lap the foot of the sheer crater face to the north and west. According to local villagers the depth of the lake in the centre is 74 feet. Sloping down to the waters' edge on the east side is a narrow shelf of volcanic ash upon which the village of Twindaung has been built.

The walls of the crater on the west and south are composed of beds of ash and débris which dip sharply away from the rim. The approach in this direction is likewise steep, as the flanks fall immediately to the level of the Chindwin River. The highest point on the crater's rim rises 500 feet above the level of the river, and viewed from the direction of the river the sides are seen to slope up in the form of a true volcanic cone.

Scattered everywhere on the outer slopes of the crater are fragments and blocks of lava, the latter sometimes measuring several feet in diameter. On the Okaing road, 1½ miles north-east from the crater's edge, one can still see large blocks of this lava strewn about on the surface of ashes.

The lava of this crater is a beautiful greyish basalt with phenocrysts of white felspar, large black glistening crystals of augite and a few small clear crystals of olivine. Besides the

blocks of olivine-basalt, some of hornblende-andesite, peridotite and pyroxenite also occur.

Branching out from the southern lip of this crater is a subsidiary ridge, marked as height 709 on the one-inch map, the level of which now rises above that of the existing rim. This ridge was formerly part of the rim itself, but it has now been dissected by a small stream course which partly separates the two. On examination it is found that the top of the ridge is capped by a thickness of ash beds ejected from the existing crater with the strewn blocks of Twindaung lava resting upon the surface. Below these beds the hill appears to be composed of soft sands in which there is an abundance of quartz pebbles. Strewn about the lower slopes of this hill are various boulders of igneous rock of very basic types, including masses of coarsely crystalline hornblende and olivine, augite and olivine, and large fragments of brown biotite. In addition to these are boulders of a metamorphic rock composed of hornblende, quartz, and large crystals of garnet, the proportion of hornblende to quartz varying in almost every boulder found; large boulders of quartz-diorite, and of an agglomerate consisting of greenish-coloured andesite with quartz-diorite also occur.

The ash beds on the river bank at Shwezaye dip locally in a south-westerly direction at an angle of 30°. They consist of layers of lava fragments between bands of finer material. Mixed with the fragments are quartz pebbles, and, more rarely, pieces of fossil wood, and small blocks of hard quartz grit. The fragmental material consists of a dark lava, differing from that of Twindaung, and occasional fragments of the ultrabasic rocks.

Thus we have centred about the Twindaung crater abundant evidence of volcanic activity during a considerable period of time, although the evidence suggests that the activity was periodic rather than continuous. For instance, it would appear that the outlying accumulations of ash in a southerly and south-westerly direction are not associated with the latest activity, but represent the remnants of extensive ash deposits which were spread out over the neighbourhood prior to the formation of the existing crater. The general shape and curvature of these remnants suggest that the old crater occupied very much the same position as the existing one, and the mass of lava blown

out during the final eruptions, part of which still exists as a wall in the present crater, was possibly a plug which filled the neck of the old vent.

That denudation proceeded apace during the lull in the periods of activity is apparent in the volcanic deposits.

**Olivine-Basalt.**—The predominant rock type in the ejected blocks from the Twindaung crater is a well-marked and highly characteristic olivine-basalt. It is compact and consists of a pale-grey matrix containing numerous large dark-green phenocrysts of augite. Besides these there are a few small phenocrysts of olivine. The felspars show every gradation from large sizes to the small stumpy ones of the groundmass. They are markedly zoned and show some resorption along the edges. Nearly all the felspars show lamellar twinning, but with a wavy extinction. The other minerals occurring as granules interstitially are mainly augite and magnetite. Some sections contain a little residual glass. There are some fine micro-vesicles in the rock which are partially filled with calcite.

The following table gives the chemical analysis [1] of a specimen, with its molecular proportions and norm :

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ - - | 47·69 | 0·795 | Orthoclase - - | 8·3 |
| $Al_2O_3$ - - | 18·20 | 0·178 | Albite - - | 21·5 |
| $Fe_2O_3$ - - | 5·26 | 0·033 | Anorthite - - | 32·8 |
| $FeO$ - - | 4·18 | 0·058 | Nepheline - - | 0·9 |
| $MgO$ - - | 6·02 | 0·150 | Diopside— | |
| $CaO$ - - | 11·57 | 0·206 | $CaO.SiO_2$ - | 10·2 |
| $Na_2O$ - - | 2·74 | 0·044 | $MgO.SiO_2$ - | 7·8 |
| $K_2O$ - - | 1·39 | 0·015 | $FeO.SiO_2$ - | 1·2 |
| $H_2O+$ - - | 1·24 | 0·068 | Olivine— | |
| $H_2O-$ - - | 0·21 | 0·011 | $2MgO.SiO_2$ - | 5·1 |
| $CO_2$ - - | Nil. | — | $2FeO.SiO_2$ - | 0·7 |
| $TiO_2$ - - | 0·80 | 0·010 | Magnetite - - | 7·7 |
| $P_2O_5$ - - | 0·36 | 0·002 | Ilmenite - - | 1·5 |
| $MnO$ - - | 0·17 | 0·002 | Apatite - - | 0·7 |
| $BaO$ - - | 0·08 | 0·001 | | |
| Total - | 99·91 | | | 98·4 |
| | | | Water - - | 1·45 |
| | | | Total - | 99·85 |

[1] Analysis by T. Marrack, A.R.S.M., M.Sc.

Other ejected blocks from the Twindaung crater include pyroxene-hornblende-andesite, hornblende-andesite, augite-peridotite, biotite-hornblende-peridotite, hornblendite (hornblende-perknite), augite-rock or pyroxenite and hornblende-schist.

**Hornblende-Pyroxene-Andesite.**—In the hornblende-pyroxene-andesite there are numerous small phenocrysts of a brown pleochroic hornblende and a few pale greenish augites, together with numerous small phenocrysts of felspar. Hornblende mostly occurs in idiomorphic hexagonal or prismatic sections. These minerals are characterised by " resorption borders " due to the interaction between the phenocrysts and the magma. In most cases the phenocrysts are corroded and the interior filled with groundmass or magnetite. The former is of a hyalopilitic nature, and finely vesicular, consisting of tiny microlites of felspar and small dark blue or opaque grains in a greyish glass.

The chemical composition of the rock as analysed by N. Sahlborn, and quoted by Conrad Burri and Hans Huber, with their molecular proportions and norm as calculated by the author, is tabulated below :

| | | Molecular Proportions. | | Norms. |
|---|---|---|---|---|
| $SiO_2$ | 56·98 | 0·949 | Quartz | 8·22 |
| $Al_2O_3$ | 18·24 | 0·178 | Orthoclase | 15·01 |
| $Fe_2O_3$ | 2·82 | 0·018 | Albite | 23·06 |
| FeO | 3·55 | 0·049 | Anorthite | 29·75 |
| MnO | 0·23 | 0·003 | Diopside— | |
| MgO | 3·98 | 0·099 | CaO.$SiO_2$ | 5·22 |
| CaO | 8·48 | 0·152 | MgO.$SiO_2$ | 3·36 |
| $Na_2O$ | 2·69 | 0·044 | FeO.$SiO_2$ | 1·50 |
| $K_2O$ | 2·55 | 0·027 | Hypersthene— | |
| $H_2O$ + | 0·33 | 0·019 | MgO.$SiO_2$ | 6·64 |
| $H_2O$ | — | — | FeO.$SiO_2$ | 2·19 |
| $TiO_2$ | 0·47 | 0·005 | Magnetite | 4·18 |
| $P_2O_5$ | — | — | Ilmenite | 0·91 |
| | | | | 100·04 |
| | | | Water | 0·33 |
| Total | 100·32 | | Total | 100·37 |

**Quartz-Diorite.**—The quartz-diorite occurring as ejected blocks is a coarse-grained rock in which the most abundant minerals are the felspars comprising both orthoclase and andesine. Quartz occurs interstitially. The ferro-magnesian minerals are not very abundant, and the crystals including hornblende and biotite, both very largely altered to chlorite, tend to be grouped together.

**Augite-Peridotite.**—The ejected blocks of augite-peridotite consist roughly of equal proportions of olivine and augite. The olivine is quite fresh, and contains no inclusions. It seems to have crystallised out shortly before the augite, by which it is sometimes enclosed. The augite is colourless and differs from the olivine in having inclusions mainly of an iron ore, probably magnetite. The only other mineral present is biotite, of which a few small flakes are seen in thin section.

**Biotite-Hornblende-Peridotite.**—The most abundant minerals in this rock are a green, strongly pleochroic hornblende and a very pale augite. The former encloses small crystals of the latter and prismatic plates of biotite. There is a considerable proportion of greenish-brown biotite, occurring interstitially in aggregates of flakes. There is only a small proportion of olivine, which originally formed large crystals, but were later corroded and partly resorbed by the magma. In many cases biotite now occupies the irregular corrosion hollows. Augite and hornblende occur intergrown, as in certain cases half of the crystal is composed of hornblende and the other half of augite, both primary.

**Hornblende-Perknite.**—Another rock-type ejected from this crater consists almost entirely of large (2 mm.) crystals of dark-green pleochroic hornblende. The only other minerals present are a few opaque grains, probably of magnetite, as inclusions, and a little brownish mineral, probably haematite, occurring interstitially. A little augite occurs in irregular patches, optically continuous and intergrown with hornblende. It is noteworthy that small crystals of hornblende are enclosed in bigger ones.

**Augite-Rock or Pyroxenite.**—Other specimens of ejected blocks consist of a group of irregular crystals of augite, upwards of an inch in length, partly on the surface of, and partly embedded in, a fine-grained granular rock of felspar (?) and augite. From the description of the ejected blocks given above it will

be seen that these craters, especially the one in question, did not experience a single explosive phase as postulated by R. D. Oldham. To the author it appears that the explosive activity comprised at least three phases in which were ejected the blocks of the following rock-types:

(1) Augite- and a biotite-augite-peridotite, hornblende-perknite and pyroxenite.
(2) Olivine-basalt.
(3) Hornblende-pyroxene-andesites, and quartz-diorite.

It is extremely unlikely that the magma could have been of such a heterogeneous composition as to yield on explosion all the types enumerated above. As a matter of further research it will be interesting to study the chemical composition of the ashes from this crater to see if their composition corresponds with those of the ejected blocks.

### (*b*) Craters on the West Bank of the Chindwin River.

About $2\frac{1}{2}$ miles south from Shwezaye Taung is a group of three craters lying contiguous to one another.

The high ground from the river bank to the edge of Taungbyauk crater, the northernmost of the three, is covered by a deposit of ash.

**Taungbyauk Crater.**—Sloping up to the crater's edge from the north, west, and east are accumulations of ash similar to those described above in the case of Twindaung. Mixed everywhere with the layers of ash as well as strewn about the surface, are small quartz pebbles.

These beds are also coated with calcareous sinter and emit the same hollow sound when traversed. They exhibit, near the crater's rim, a slightly undulating surface transverse to the direction of slope.

The inner walls of the crater are precipitous and usually composed of ash deposits with lava fragments and blocks. The rim is highest to the north-east, where a solid wall of lava is exposed. (See Plate V, Fig. 1). The lava is an olivine-basalt, and differs further from the basalt and andesite of Twindaung in that large phenocrysts are not evident.

The crater measures approximately half a mile in diameter

from rim to rim and averages about 200 feet in depth. The floor is now partially covered by a small lake which is fed by fresh-water springs at its edge.

Ejected blocks of lava from this crater consist of a greyish rock in which flow structure is well marked by lines of elongated vesicles. A thin section shows numerous phenocrysts of olivine which are altered along the edges and cracks to serpentine. The phenocrysts of augite are smaller, and in contrast to the majority of rocks from the Lower Chindwin region are a brownish-green, while in others, of a normal greenish colour. The groundmass is coarser grained than in most of the lavas of the district and there is a marked fluxional arrangement of the long, lath-shaped felspars. Occurring interstitially are abundant crystals and granules of augite and numerous grains of magnetite. The residual material resembles that of the rocks from Kyaukkadaung. It is colourless, with a feeble double refraction, and shows wavy extinction. The refractive index is lower than the felspar laths. The lava from this crater is very similar to the picrite-basalt of Kyaukkadaung.

A chemical analysis [1] of a typical specimen of the olivine-basalt with its molecular proportions and norm is tabulated below :

| | | Molecular Proportions. | | Norms. |
|---|---|---|---|---|
| $SiO_2$ | 47·28 | 0·788 | Orthoclase - | 7·23 |
| $Al_2O_3$ | 15·28 | 0·150 | Albite - | 17·03 |
| $Fe_2O_3$ | 5·58 | 0·035 | Anorthite - | 27·52 |
| FeO | 3·93 | 0·055 | Nepheline - | 1·56 |
| MgO | 9·43 | 0·235 | Diopside— | |
| CaO | 12·77 | 0·228 | $CaO.SiO_2$ | 11·83 |
| $Na_2O$ | 2·36 | 0·038 | $MgO.Sio_2$ | 11·20 |
| | 1·23 | 0·013 | $FeO.SiO_2$ | 1·06 |
| | 0·61 | 0·033 | Olivine— | |
| $H_2\bar{O}$ | 0·33 | 0·019 | $2MgO.SiO_2$ | 8·61 |
| $CO_2$ | — | — | $2FeO.Sio_2$ | 1·02 |
| $TiO_2$ | 0·49 | 0·006 | Magnetite - | 8·12 |
| $P_2O_5$ | 0·42 | 0·003 | Ilmenite - | 0·91 |
| MnO | 0·18 | 0·003 | Apatite - | 1·01 |
| BaO | 0·05 | | | |
| | | | | 97·10 |
| | | | Water | 0·94 |
| Total - | 99·94 | | Total | 98·04 |

[1] Analysis by T. Marrack, A.R.S.M., M.Sc.

**Taungbyauk.**—The southern rim of Taungbyauk crater is no longer intact, but has been partly obliterated by ash deposits thrown out from the middle crater of the group, into which the ashes dip at an angle of 30°, and it would appear, therefore, that the middle crater was formed after the outline of the first had been established. This middle crater is not so clearly defined as the others. There is no lake covering the floor, which is partly silted up, and is now under cultivation.

**Twin Taung.**—Between the middle and southern craters of the group of three is a hill marked as point 812 on the one-inch map. This hill rises some 550 feet above river level and is the highest point in the neighbourhood. (See Plate V, Fig. 2.) It has been built up by a great thickness of ash accumulations, which do not appear to be associated with the deposits from the existing craters, and must therefore represent the remnants of the ash deposits which were originally spread over the neighbourhood. This hill, Twin Taung, must not be confused with Twindaung, the craters on the other side of the River Chindwin.

**Twinywa Crater.**—This crater (see Plate V, Fig. 2) is the southernmost of the group of three. It is the largest in diameter, measuring as much as three-quarters of a mile across. It is very shallow compared with its width, averaging not more than 150 feet in depth. No wall of lava is exposed. The ash beds, comprising a thickness of from 30 to 50 feet, are spread out over Irrawaddy sands and form the rim of the crater. The soft sands are well seen below the ash deposits and form the lower slopes of the sides and floor. The usual fragments and blocks of lava are strewn about the slopes and outer surface. The inner wall of the crater slopes gradually inwards to the edge of a lake, nearly half a mile across, which now covers the greater portion of the floor.

The chemical analysis [1] of the olivine-basalt from the Twinywa crater with its molecular proportions and norm are tabulated on next page.

According to Professor Conrad Burri the analysis shows higher alkalies than ordinary basalts, and the rock may well be compared with nepheline-bearing lavas (basanites, berondrites,

[1] Analysis by S. Parker.

etc.), which is confirmed by the norm. The actual rock, however, contains no nepheline and also no glass. The augite must, therefore, contain some alumina and alkalies, and the plagioclase, perhaps some carnegieite molecules. The occurrence of calcite and the "reversed" zoning of augite from calcium-poor towards calcium-rich suggest probable assimilation of limestone by the rock, most probably from the Pegu Series.

| | | Molecular Proportions. | | Norms. |
|---|---|---|---|---|
| $SiO_2$ | 44·66 | 0·744 | Orthoclase | 6·67 |
| $Al_2O_3$ | 15·14 | 0·148 | Albite | 3·88 |
| $Fe_2O_3$ | 6·03 | 0·038 | Anorthite | 18·33 |
| $FeO$ | 2·50 | 0·035 | Nepheline | 17·45 |
| $MnO$ | 0·09 | 0·001 | Diopside— | |
| $MgO$ | 10·21 | 0·255 | $CaO.SiO_2$ | 18·79 |
| $CaO$ | 13·38 | 0·239 | $MgO.SiO_2$ | 16·20 |
| $Na_2O$ | 4·29 | 0·069 | Forsterite | 6·51 |
| $K_2O$ | 1·13 | 0·012 | Magnetite | 3·02 |
| $H_2O+$ | 0·32 | 0·018 | Ilmenite | 3·50 |
| $H_2O-$ | 0·04 | 0·002 | Haematite | 4·00 |
| $CO_2$ | 0·40 | 0·009 | Apatite | 0·13 |
| $TiO_2$ | 1·85 | 0·023 | Calcite | 0·90 |
| $P_2O_5$ | 0·05 | 0·001 | Water | 0·32 |
| Total | 100·09 | | Total | 100·00 |

**Leshe Craters.**—Two miles to the south-west of Twin Crater are the compound craters of Leshe, which exhibit the same characteristics as those described above and are surrounded on all sides by a superficial covering of ash deposits which slope gradually up to the rim. No wall of lava is exposed in the crater, and the ash beds are seen to rest upon unaltered Irrawaddy sands, which form the lower slopes and the floor of the depression.

**Banbwe.**—Immediately north of Banbwe village, which is situated about four miles to the south-east of Leshe, there is an isolated ridge of ash beds with a precipitous face to the north. This occurrence lies to the south of the Yinbo *chaung*, which has produced a plain to the north of the village separating this ridge from the main ash deposits to the north-west. It would appear that this isolated occurrence of older volcanic tuff of a basaltic nature is a remnant of the deposits which were once scattered over the neighbourhood rather than derived from

a crater additional to the above. There are several isolated occurrences in the immediate neighbourhood which were all derived from a common centre. The original deposits were spread out over soft Irrawaddy sands which are rapidly removed by sub-aerial denudation, and thus it is that the existing remnants of to-day are usually confined to the higher levels.

The bulk of the volcanic activity appears to have been centred about Twindaung and Taungbyauk, especially the former, and it is clear that these two craters mark the sites of older vents, now obliterated, which were in activity for a considerable period following upon the close of Irrawaddy times. It would appear, further, that the existing craters were formed subsequently to the cessation of former activities after the original deposits had been much modified in form by denudation.

The accumulations of ash beds with lapilli four and a half miles distant from the centre of eruption (Twindaung), the quantity of débris strewn about the outer surface of the cones, all bearing jagged edges as though they had been torn away from a larger mass without the smoothing action of heat, and, finally, the fragmental nature of the cones themselves, all point to an explosive type of eruption.

The successive layers of coarse lapilli, several inches in thickness, between thin layers of fine material, throughout a thickness of some 50 feet of deposits, confirms the suggestion advanced above that the craters were not formed by one violent explosion, but were gradually built up by a series of explosive eruptions which must have extended over a considerable period of time.

The absence of evidence of any extensive lava outpourings from these craters is peculiar, especially as there occur in the vicinity thick sheets of andesitic and basaltic lavas which have obviously been poured out from some vent, but which are not accompanied by ash accumulations. It would appear that the eruptions in the region varied from violently explosive at one extreme to gentle outpourings of sheets of lava at the other.

At Natlabo village on the east bank of the Chindwin River and 3 miles south of Wunbo, 4 miles south of the Twindaung crater and 3½ miles east of the Taungbyauk crater, a sheet of lava, 10 to 20 feet thick, resting upon Irrawaddy sands, can be observed from the river.

On the east bank of the Chindwin river opposite Natlabo North (22° 18′, 95° 2′) a cliff of basaltic tuff, similar to that of the other craters, stands conspicuously over the river, accompanied by huge blocks of basalt. The latter suggest the proximity of the source, but no crater actually exists in the vicinity.

## The Southern Volcanic Occurrences on the West Bank of the Chindwin River.

**Minma.**—One mile south of the Leshe craters at Minma in the Yinbo *chaung* masses of lava are exposed. Rising from the *chaung* on the south side of the village are two plateau-like elevations marked on the map as the Myetthadaung, which are capped by a sheet of lava (vesicular dark olivine-basalt), resting apparently on quartzites. The rock is composed of phenocrysts of olivine, augite, hornblende and plagioclase, embedded in a groundmass of the same minerals with abundant laths of felspar and a little glass occurring interstitially. In the Yinbo *chaung*, half a mile to the west of Myetthadaung and west of Minma village, is an outcrop of granite. This granite is coarse-grained with small flakes of yellow mica. It is very much decomposed at the surface and crumbles in the fingers.

**Silaung Taung.**—Three and a half miles south-east of Minma and three miles south-south-west of Banbwe is an elevated plateau of about one and a quarter miles in length and some three-quarters of a mile in width, known as the Silaung Taung. This plateau rises about 150 feet above the level of the surrounding country, and is capped by a horizontal sheet of lava, at least 50 feet in thickness, which presents a vertical cliff at its extremities. It is composed of a dark-grey olivine-basalt. Pink calcareous sinter with embedded fragments of basalt is met with some way down the slope of the hill. There is no evidence of a vent in the immediate vicinity. It appears to be of very recent date and must have been poured out from a neck which is now concealed by the flow. There are a few disintegrated blocks round the immediate edges of the flow, but they do not extend outwards for any distance.

Immediately south of the Silaung Taung and west of Silaung village is an outcrop of granite much decomposed at the surface.

It is coarse-grained with pink felspar. Traced northwards along the Yinmadaw *chaung* it is found outcropping only in the *chaung* bed. It passes into hornblende-granite-porphyry with whitish phenocrysts of felspar.

One mile west of Silaung Taung another broad, plateau-like elevation is covered by an old green basalt, interbedded in places with quartzite. The basalt is highly decomposed, but the chief interest of the exposure lies in the occurrence in it of a variety of intrusive rocks.

One mile east of Taungbu (22° 12′, 94° 57′) is an occurrence of granophyre, a very compact rock, grey in colour; with white crystals of felspar and quartz. The thin sections show an interesting gradation from the cryptocrystalline to a perfect spherulitic texture. The interspaces between the spherulites are occupied by a crypto-granular mixture of quartz and felspar, passing into a cryptographic intergrowth on the margins of the spherulities, and this in its turn develops a true spherulitic texture towards the centres. The spherulitic texture is sometimes seen developing round nuclei of quartz and felspar phenocrysts. According to Sondhi, other varieties are met with in small streams north of Taungbu.

**Songyaung.**—On the right bank of the Chindwin river, opposite Alon and two miles east of Songyaung, is a low hill extending in a north-west—south-east direction, with gentle slopes on all sides except the north, where it ends abruptly over a shallow lake, with a scarp about 100 feet in height. This lake is deeply truncated near the north-eastern side and marks the site of an extinct crater. That part of the hill which abuts on the river, according to Sondhi,[1] is composed of a highly jointed, comparatively fresh, dark, olivine-basalt, which in thin sections shows phenocrysts of olivine in a groundmass consisting of felspar laths, minute grains of olivine, augite and magnetite dust. A little way from the river the basalt becomes highly scoriaceous and vesicular. Farther west it is replaced by a very characteristic bed, about six feet thick, of lapilli cemented by a sparse amount of volcanic ash. To the south-west of the lapilli bed occur a number of unconsolidated beds of basaltic tuff, with a quantity of quartz pebbles, sand and fossil wood. At different

[1] *Rec. Geol. Surv. Ind.*, vol. lxi, 1928, p. 105.

horizons in this deposit beds of fine volcanic dust and ash occur, which are often finely laminated. Repetition of the beds of coarser pyroclastic material and laminated volcanic dust marks the different phases of the explosive energy of the crater, and suggests that the material was deposited by a series of rapid explosions of varying intensity and short duration. The general dip of the deposit is to the south, but near the centre of activity it is variable in direction as well as in degree.

**Kyaukmyet Hills.**—The Kyaukmyet hills are composed of very compact rhyolites and quartz-porphyries with interbedded quartzites.

A liparite from this locality was first described by Kelterborn.[1] It is a dense rock which shows some iron pyrites and biotite to the naked eye. The microscope reveals the biotite to be corroded with formation of opaque ore, while sections of corroded quartz are also present. The groundmass is microfelsitic and consists of quartz and slightly turbid felspar. The texture must originally have been vesicular, but the cavities are now all filled with a coarse-grained quartz mosaic. This must have been brought about by hydrothermal silicification after the consolidation of the rock. Below is quoted the chemical analysis of the rock as given by Kelterborn. Professor Conrad Burri of Zurich has compared it with analyses of similar rocks.

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| $SiO_2$ - | 74·95 | 76·04 | 75·34 | 73·62 |
| $Al_2O_3$ - | 12·04 | 12·17 | 12·51 | 14·24 |
| $Fe_2O_3$ - | 0·24 | 1·25 | 0·42 | 0·93 |
| FeO - | 2·54 | 1·11 | 1·55 | 0·67 |
| MgO - | 0·77 | 0·19 | 0·32 | 0·33 |
| CaO - | 0·50 | 1·68 | 1·07 | 1·07 |
| $Na_2O$ - | 3·11 | 3·65 | 3·31 | 3·25 |
| $K_2O$ - | 3·66 | 3·02 | 4·17 | 4·28 |
| $H_2O$ + | 2·08 | 1·05 | 0·86 | 1·29 |
| $H_2O$ − | — | 0·08 | — | — |
| $TiO_2$ | 0·25 | 0·05 | 0·00 | 0·21 |
| $P_2O_5$ | — | 0·00 | 0·00 | 0·02 |
| MnO | — | — | 0·07 | 0·10 |
| Incl. | — | — | 0·42 | 0·08 |
| Total - | 100·14 | 100·29 | 100·04 | 100·09 |

[1] *Ecol. Geol. Helv.*, vol. xix, 1925, pp. 352-359.

I. Mica Liparite, Pagoda of Kyaukunyat, Lower Chindwin River, Upper Burma. Anal. F. Hinden in P. Kelterborn, *Ecol Geol. Helv.*, vol. xix, 1925, p. 359.

II. Perlite, Milos. Anal. Raoult in A. Lacroix, *Liv. Jub. Soc. Geol. Belgique, Liège*, 1926, p. 400.

III. Rhyolite, Elephant's Back, Yellowstone National Park, U.S.A. Anal. J. Whitfield in J. P. Iddings, *U.S.G.S. Mem.*, vol. xxxii, ii, 1899, p. 426.

IV. Rhyolite, State Creek, Tehama Co., Calif., U.S.A. Anal. W. F. Hillebrand in J. S. Diller, *U.S.G.S. Bull.* 148, 1897, p. 192.

The molecular proportions and the norm of the rock as calculated by the author are tabulated below :

| | Molecular Proportions. | | Norm. |
|---|---|---|---|
| $SiO_2$ | 1·249 | Quartz | 39·18 |
| $Al_2O_3$ | 0·118 | Orthoclase | 21·13 |
| $Fe_2O_3$ | 0·001 | Albite | 26·20 |
| FeO | 0·035 | Anorthite | 2·50 |
| MgO | 0·019 | Corundum | 2·14 |
| | | Hypersthene— | |
| CaO | 0·009 | $MgO.SiO_2$ | 1·90 |
| $Na_2O$ | 0·050 | $FeO.SiO_2$ | 4·09 |
| $K_2O$ | 0·038 | Magnetite | 0·23 |
| $H_2O$ + | 0·115 | Ilmenite | 0·46 |
| $H_2O$ – | — | | |
| $TiO_2$ | 0·003 | | 97·83 |
| $P_2O_5$ | — | | |
| MnO | — | Water | 2·08 |
| | | Total | 99·91 |

The analysis, as tabulated above, shows some unusual characters. Liparites of the same silica-content contain generally less iron and the rocks with the same iron-content are richer in silica. This also confirms that the rock has undergone silicification. The slight excess of alumina over alkalies and lime indicates that the rock is not absolutely fresh.

**Myayeik Taung.**—The main hill is composed of silicified rhyolite with blocks of quartzite, while the small hill to the west is built of shattered quartzite and highly altered basalt. In the Yinmadaw *chaung* to the south-west are masses of epidiorite

which appear to rest against a decomposed holocrystalline rock composed of white felspar and small black biotite crystals. East of Myayeik there is another small hill of purple quartz-porphyry.

**West Monywa Group.**—The conical-shaped hills 994, 943 and 937, immediately south of the Yama *chaung*, and hills 1055 and 995, five miles to the south-east and on the south side of the Ywashe-Yinmabin road, which are so prominent in the landscape looking westwards from Monywa, are composed of white and bluish-grey rhyolites, rhyolitic breccias, agglomerates and indurated tuffs. They have undergone hydrothermal and metasomatic alteration. Haematite occurs in the form of veins and botryoidal masses in these rocks. The ores of copper, malachite and azurite are also present in the form of veinlets and impregnations. Exploitation of the copper ore has been attempted by shafts and tunnels sunk into the volcanic rock, but the ore occurs in quantities too minute to be won on a commercial scale.

In the stream bed to the south of hill 937 are bedded rhyolites dipping steeply to the south.

**Ninth Mile, Yinmabin Road.**—Just past the ninth mile on the Ywashe-Yinmabin Road, where the road commences the descent to the village of Kaungzin, are outcrops of an interesting rock which seems to differ from all others in the Chindwin region. It is a glassy hypersthene-andesite in which phenocrysts of andesine-labradorite felspar and hypersthene are observed in thin sections. The former are quite colourless, and either wholly or partially enclose crystals of the hypersthene. The interior of some of the large crystals of felspar is filled with minute crystals of magnetite or inclusions of the groundmass. Hypersthene in some sections is altered to bastite. A few crystals of augite are visible, but they are considerably subordinate in proportion compared with the hypersthene. The groundmass, of which magnetite forms a considerable proportion, is mostly glassy with occasional small crystals of felspar and hypersthene.

A few miles farther south are the igneous occurrences of the Ingyin *taung* and Powin *taung* area, which consist of andesites, rhyolitic agglomerates and fine-grained ashes and tuffs interbedded with the Pegu Series, and intrusions of coarse diorites and mica-porphyries. The andesites have locally been silicified

and the vesicles of the amygdaloidal rock have been filled with chalcedony in beautifully radiating fibres. The ashes and tuffs have undergone pronounced metamorphism brought about most probably by the intrusion of adjacent diorites. As a result, sericite and slaty cleavage have developed and the rocks have a marked schistose appearance.

**Salingyi.**—According to C. T. Barber the intrusive and extrusive rocks of the Salingyi uplands consist of dacites, dolerites, epidiorites and coarse-grained diorites. These rocks have undergone pronounced dynamo-metamorphism accompanied by far-reaching mineralogical changes, the chief of which are saussuritisation of the felspars and uralitisation and epidotisation of the ferro-magnesian minerals. There also occurs an intrusion of granitic rock into typical dolerites in the neighbourhood of Saga (95° 8′, 21° 57′) and the intrusion of a pegmatite dyke into coarse diorite, one and a half miles south-east of Kyaunggon (95° 6′, 21° 58′). Barber adds, moreover, that the general configuration and petrological characters of the igneous masses are such as to leave little doubt that they were formed as laccolitic intrusions into the Pegus, the sedimentary cover having been removed by denudation.

**Linzayet.**—At Linzayet eight and a half miles to the south of Salingyi is a small mass of lava, a hundred feet or so in diameter, which also appears to have been intruded into sands of Pegu age, chiastolite being developed near the contact. The Pegu rocks dip towards this intrusion at steep angles. This occurrence is of similar type to hill 1260, and the other intrusions in the East Monywa Hill Belt, described below.

**Shinmadaung.**—The volcanic rocks of the Shinmadaung area consist of hornblende-andesite, basalts, ashes and rhyolitic agglomerates and breccias. Occurring immediately beneath the basal red bed of the Irrawaddy Series on the west flank of the Shinmadaung inlier, west of Kabauk village, are to be found conglomerates and rhyolite breccia. They lie on the west side of the main strike fault and outcrop as a narrow band, broadening to the south, over a distance of some six miles, and running in a north-north-west to south-south-east direction. Some doubt exists as to the age of these rocks, but, according to E. S. Pinfold and A. E. Day, they appear to represent a period of

specialized volcanic activity contemporaneous with the deposition of the basal beds of the Irrawaddian; while Barber[1] states that they occupy a belt along the Pegu-Irrawaddian boundary and that the presence of ashes and rhyolitic agglomerates interbedded in the Pegu Series has been clearly demonstrated.

There are, in addition, small intrusions of a doleritic rock in beds of Pondaung age which are exposed in this inlier. They also occur mainly along the line of the strike fault.

One of the most interesting volcanic occurrences in this range, also on the line of the main strike fault, is a sheet of lava forming a high plateau-like elevation to the north of Thayet-pingan, which recalls the Silaung sheet, described above.

This sheet of basalt, one and a half miles in length and over a mile in width, is obviously of sub-recent origin. It is composed of loose blocks and is clearly a flow emerging from a neck probably near the centre of the sheet. The edges frequently form sheer precipices, and the flow is so recent that few of the blocks have been disturbed. Further proof of its recent age is the way the blocks flow round the local topographic summits—the flow descending into small valleys and piling itself up against summits which could not be over-ridden.

The majority of the igneous developments in this inlier took place along the line of the main fault.

### (c) The Volcanic Occurrences of the East Monywa Hill Belt.

The volcanic occurrences in this belt from south to north are as follows:

**Hill 1260, or Kyaukkadaung** (22° 8′, 98° 6′).—The hill is situated about nine miles east and a little north of Monywa, and occurs close to the western flank of the Pegu inlier. It is elliptical in shape, the longer axis of the ellipse running a few degrees north of east. There are three blunted peaks, the centre or highest rising some 800 feet above the alluvial plain, which stretches away to the west. The core of the hill is composed of a very basic basalt, completely surrounded by Pegu rocks, and appears to lie on the line of the main fault, which is in evidence to the south on the west side of Taunggya village.

[1] *Rec. Geol. Surv. Ind.*, vol. lx, 1927, p. 87.

Actual contacts between lava and the country rock are generally concealed, but unaltered exposures of the Pegu sands and shales can be found high up the southern slopes of the hill. An exposure of shale quite close to the contact is much crushed and has, in parts, a reddish burnt appearance. The Pegu rocks to the south, and on the west side of the main fault, dip steeply away from the mass. Dips in the Taunggya *chaung*, on the east side of the fault, are generally low, but irregular, dipping first in one direction and then in another. It is particularly noticeable that blocks of the lava are not widely scattered, and what blocks there are belong to the talus on the slopes and stream beds at the immediate foot of the hill.

The extent of the actual mass of the igneous rock is about a mile in length and a quarter of a mile in width.

**Hill 779** (22° 13′, 95° 18′).—This intrusion of igneous rock lies about seven miles to the north-east of Hill 1260, on the south bank of the Thazi *chaung* between the villages of Thazi and Sulegon. The igneous mass is elliptical in shape, with the longer axis running a few degrees west of north, and is thus slightly oblique to the Pegu sands, in which it occurs, and which strike about north 10° east. It is situated well within the Pegu inlier some three miles east of the main fault. It is half a mile in length and quite narrow.

The rock *in situ* on the crest of the hill, where it stands up as a solid wall, is a basic olivine-basalt similar to that of Hill 1260, though some specimens are less basic. It is compact and dark-grey in colour. Phenocrysts of olivine and dark-green augite are visible.

Petrologically both the Kyaukkataung, 1260 Hill, and the Hill marked 779 are composed of picrite-basalt which is a greyish rock, sometimes spotted with phenocrysts of pyroxene and olivine. A thin section shows phenocrysts of an iron-rich olivine with some clino-enstatite. Most of the augite is in the groundmass, but there are a few crystals of larger size which tend to be aggregated together. In some sections both true augite and diopside occur together. Sometimes there are numerous large crystals of magnetite. The groundmass is fine-grained and consists mainly of small crystals and microlites of green augite, with numerous grains and granules of magnetite. There are a

few definite laths of felspar. The residual material is colourless and for the most part doubly refracting. In places under high powers shadowy outlines with a limpid appearance and very low double refraction suggest analcite. Sometimes the groundmass consists of a glassy base packed with granules of augite, grains of magnetite and tiny laths of felspar. In places the vesicular varieties are lined with zeolites, the growth of which took place in two or more stages, each consisting of radiating fibrous needles. In places the vesicles are filled wholly or partially with calcite.

The picrite-basalts described by Professor Holmes from Mozambique are alkaline rocks, with purple titaniferous augite as are the comparable Hillhouse basalts. The present rocks differ mainly in the character of the augite.

A chemical analysis [1] of a picrite-basalt from Kyaukkadaung yielded the following results, and its molecular proportions and norm are also calculated below :

| | | Molecular Proportions. | | Norms. |
|---|---|---|---|---|
| $SiO_2$ | 47·10 | 0·785 | Orthoclase - | - 5·56 |
| $Al_2O_3$ | 16·32 | 0·160 | Albite - | - 16·24 |
| | 3·80 | 0·024 | Anorthite - | - 33·08 |
| | | | Diopside— | |
| FeO | 5·00 | 0·069 | $CaO.SiO_2$ | - 9·63 |
| MgO | 11·65 | 0·291 | $MgO.SiO_2$ | - 7·25 |
| CaO | 11·45 | 0·205 | $FeO.SiO_2$ | - 1·38 |
| $Na_2O$ | 1·95 | 0·031 | | |
| | | | Hypersthene— | |
| | 0·87 | 0·010 | $MgO.SiO_2$ | - 1·65 |
| | 0·50 | 0·028 | $FeO.SiO_2$ | - 0·33 |
| $H_2O$ – | 0·40 | 0·022 | | |
| | | | Olivine— | |
| $CO_2$ | Nil. | Nil. | $2MgO.SiO_2$ | - 14·14 |
| $TiO_2$ | 0·35 | 0·005 | $2FeO.SiO_2$ | - 3·06 |
| | 0·18 | 0·001 | Magnetite - | - 5·57 |
| MnO | 0·25 | 0·003 | Ilmenite - | - 0·76 |
| S | Traces | — | Apatite - | - 0·34 |
| Total | 99·82 | | | 98·99 |
| | | | Water - | - 0·90 |
| | | | Total | - 99·89 |

[1] Analysis by W. H. Herdsman.

**Hill 822, or Thazi Hill** (22° 17′, 95° 15′).—This occurrence of igneous rock is conical in shape and lies on the line of the main fault on the edge of the Pegu inlier, apparently within Pegu sands, Irrawaddy sands, and alluvium.

The lava of Thazi hill has also been described[1] as picrite-basalt, though less basic than that of the Hill 1260, but not widely differing from it. It is a dark-grey rock. The most abundant mineral under the microscope is augite, varying in size from small phenocrysts to granules in the groundmass. There are small patches of serpentine, perhaps pseudomorphous after olivine. Plagioclase felspar occurs both as phenocrysts and also in the groundmass. The latter resembles that of the normal rock of Hill 1260, consisting of laths and microlites of felspar, small crystals and granules of augite, grains of magnetite and a colourless residue. Some of the vesicles are filled with calcite. It will be noted that the rock under description differs from those of Hills 1260 and 779 in the relative paucity of olivine and in the presence of a small proportion of plagioclase amongst the phenocrysts. A chemical analysis[2] of the specimen from this locality with its molecular proportions and norm is tabulated below:

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| | 46·72 | 0·779 | Orthoclase | 8·90 |
| $Al_2O_3$ | 14·93 | 0·146 | Albite | 14·93 |
| | 5·12 | 0·032 | Anorthite | 26·69 |
| FeO | 3·98 | 0·056 | Nepheline | 1·56 |
| | | | Diopside— | |
| MgO | 8·70 | 0·218 | $CaO.SiO_2$ | 14·92 |
| CaO | 12·87 | 0·231 | $MgO.SiO_2$ | 12·20 |
| | 2·12 | 0·034 | $FeO.SiO_2$ | 0·92 |
| $K_2O$ | 1·45 | 0·016 | Olivine— | |
| $H_2O+$ | 2·30 | 0·128 | $2MgO.SiO_2$ | 6·72 |
| $H_2O-$ | 0·55 | 0·030 | $2FeO.SiO_2$ | 0·61 |
| $CO_2$ | Nil. | — | | |
| $TiO_2$ | 1·10 | 0·014 | Magnetite | 7·42 |
| $P_2O_5$ | 0·27 | 0·002 | Ilmenite | 2·13 |
| BaO | 0·08 | 0·001 | Apatite | 0·67 |
| | | | | 97·67 |
| | | | Water | 2·85 |
| Total | 100·39 | | | 100·52 |

[1] *Trans. Min. Geol. Inst. Ind.*, vol xxi, 1927, pp. 191-192.

[2] Analysis by T. Marrack, A.R.S.M., M.Sc.

**Inde Hill**, 800 feet (22° 24′, 95° 13′).—This is the most interesting occurrence within the hill belt, as it bears visible evidence as a centre of volcanic activity: remnants of a crater and deposits of volcanic ash occur, similar in every way to the deposits accompanying the explosive craters about Shwezaye. It can, in fact, be included as one of the group as its age and mode of occurrence are identical, but, instead of appearing on the same lines as the other craters, it is situated 10½ miles to the east of Ywatha, the northernmost of the group, and obviously occurs on the line of the main fault which runs the length of the East Monywa Pegu inlier.

The village of Inde rests upon a narrow belt of alluvium, but immediately to the south are beds of volcanic ash which curve round to the spur of Hill 800. In a stream bed about one mile south of the village beds of ash rest upon sands apparently of Irrawaddian age. These deposits of ash are from 10 to 15 feet thick and consist of layers of coarse lapilli between much finer material. In the coarse layers are occasional blocks of lava up to a foot in diameter. These beds are not consolidated, and where they overhang the walls of the *chaung* they break into heaps of grey cindery powder.

The ash deposits on the spur to the north of Hill 800 rest upon Irrawaddian sands, and farther north, where the ash beds have died out, blocks of lava can still be seen strewn about the surface of the sands and extend thus as far as the stream bed to the north-east of Myothit Chaung village.

The inward slopes of Hill 800 and spur present a precipitous face which is evidently a remnant of the crater walls. The northern and western walls have been removed by denudation and the floor is now silted up.

The lava ejected from this crater is a normal olivine-basalt with phenocrysts of olivine, rendered opaque red by oxidation on the exposed surfaces of the rock.

The eruptions of this crater were apparently of the explosive type, but the successive layers of coarse ash and fine material throughout the thickness of the deposits point to a series of explosive eruptions extending over a period of time rather than to one violently explosive outburst.

The age of this volcano is clearly sub-Recent, as is proved by

the deposition of the ejected material upon the uppermost Irrawaddian sands.

The rock of Hill 800 is a dark grey olivine-basalt, which in places is vesicular. Numerous glassy phenocrysts of olivine are visible. Under the microscope it consists of numerous phenocrysts of greenish augite, which tend to occur in aggregates and a few hypidiomorphic or idiomorphic olivines which are perfectly clear. Numerous skeleton crystals of olivine also occur, where the interior has been corroded and filled with groundmass. The phenocrysts of plagioclase felspar, which are often stellately aggregated, are clear and scattered irregularly through the rock. Sometimes, however, the felspars are zoned and the plagioclase is as basic as labradorite. In some sections augite and felspar seem to have crystallised simultaneously. The groundmass consists of abundant granules and small crystals of augite and grains of magnetite interspersed with lath-shaped felspars. There is a small amount of residual glass, conspicuous by its dark brown colour. In some sections calcite also occurs in irregular patches, in places partially filling the vesicles.

**Okpo Letpan** (22° 29′, 95° 14′).—Okpo Letpan is an isolated hump-shaped hill standing 400 feet above the level of the surrounding plain, which is floored by sands of Irrawaddian age. The hill lies about seven miles north of Inde and three miles north by north-east of the volcanic bed at the twenty-sixth milestone described above. The extrusive rock is of medium thickness and appears to dip steeply to the north.

The lava is much decomposed at the surface and can be dug into with a knife blade ; it differs from the igneous rocks of the other occurrences, except those of Hill 800 and the twenty-sixth milestone just described, in that it contains visible phenocrysts of white felspar.

The lava from this hill is a rough textured olivine-basalt, full of vesicles of all sizes. It is of a greenish-grey colour, speckled with numerous red-brown crystals of altered olivine and augite, often aggregated together with smaller crystals of felspar. The very fine-grained groundmass contains tiny microlites, probably of augite, which tend to cluster round the edges of larger felspar crystals, together with grains of magnetite. There appears to be a little residual colourless glass.

A chemical analysis of the typical olivine-basalt from Okpo yielded the following results.[1] The molecular proportions and the norm of the specimen are also tabulated below :

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ | 46·26 | 0·771 | Orthoclase | 6·12 |
| $Al_2O_3$ | 16·68 | 0·164 | Albite | 24·89 |
| O | 7·77 | 0·048 | Anorthite | 28·91 |
| | | | Nepheline | 0·42 |
| | | | Diopside— | |
| FeO | 2·41 | 0·033 | $CaO.SiO_2$ | 10·67 |
| MgO | 5·71 | 0·142 | $MgO.SiO_2$ | 9·20 |
| CaO | 13·43 | 0·240 | Forsterite | 3·50 |
| $Na_2O$ | 3·06 | 0·049 | Magnetite | 5·10 |
| $K_2O$ | 1·00 | 0·011 | Haematite | 4·16 |
| $H_2O+$ | 0·59 | 0·032 | Ilmenite | 1·98 |
| $H_2O-$ | 0·19 | 0·010 | Apatite | 0·67 |
| $CO_2$ | 1·67 | 0·038 | Calcite | 3·08 |
| $TiO_2$ | 1·07 | 0·013 | | |
| | 0·31 | 0·002 | | 99·42 |
| | 0·16 | 0·002 | | |
| BaO | 0·03 | | Water | 0·78 |
| | 100·34 | | | 100·20 |

*Hypersthene basalt.*—Hypersthene basalt, which contains phenocrysts of felspar and pyroxene, has also been described from Okpo. The latter includes both the orthorhombic and monoclinic species. Magnetite occurs both as inclusions in these phenocrysts and in the groundmass. The hemicrystalline groundmass contains small laths of felspar, and small granules of augite and magnetite.

*Tachylyte* (?) *and Nepheline-Tachylyte*—The tachylyte is a compact flinty-looking rock of dark-grey colour with a few cracks filled with calcite. It is possible that this represents the glassy margin of the flow.

The nepheline-tachylyte, under the microscope, consist of a few small irregular crystals of felspar with reaction rims. The remainder of the rock consists of a dark-coloured base, which under high powers resolves itself into a mass of tiny colourless crystals, black dots and residual glass. The colourless crystals appear to be nepheline. The whole rock is very vesicular, and

[1] Analysis by T. Marrack, A.R.S.M., M.Sc.

some of the vesicles show fibrous radiating growths, apparently of zeolites.

**The Natyindaung Mass.**—Natyindaung (22° 30′, 94° 59′). This is an isolated occurrence of igneous rock, unassociated with the East Monywa Hill belt inlier, lying some distance to the west, in an area floored by uppermost Irrawaddian sands. It is of special interest as actual contacts with the soft sands can be seen. It closely resembles Okpo Letpan in shape, occurring as two hump-shaped hills with an intermediate depression.

The southern mass is the smaller of the two, and rises from the south in the form of a narrow dyke. The joint planes are vertical, and the rock, broken into flags, stands up with a typical dyke-like appearance. No sharp contact with the country rock can be seen, but the rectangular blocks of the rock get smaller and smaller and finally pass into an agglomeration of sand and small pieces of igneous rock. As the rock rises it loses its dyke-like appearance and stands up as a massive wall, which breaks up into large irregular blocks. As the contact is reached on the west flank the rock similarly breaks up into smaller and smaller blocks, but here the jointing is horizontal, giving the lava a bedded appearance.

The longer axis of the combined masses is north and south. Both sheets appear to dip steeply to the east, but the horizontal jointing at the base of the mass on the west flank suggests rather that the sheet was bent over to the horizontal at its uppermost extremity.

The igneous rock varies much in texture and colour according to position. In some cases, generally near the contact, as in the southern exposure, it has a compact blackish appearance. Higher up, where it is more massive, it is finely crystalline, a light-grey in colour, and very hard. On the northern hill it is generally darker in colour, sometimes compact and sometimes exceedingly scoriaceous. A ferro-magnesian mineral occurs as phenocrysts, but is generally oxidised to a red rusty powder. For the most part the rock is a basic olivine-basalt not very different from that of Hill 1260.

The lava is of a grey colour and shows orange-yellow phenocrysts of olivine together with a few black pyroxenes. The specific gravity of the rock is 2·86. Under the microscope a thin

section shows phenocrysts of olivine and augite. The former mineral is largely altered: nearly all the crystals have a broad brown border of haematite and in small crystals there is no original olivine left. Inclusions of magnetite and haematite are common, and some of the crystals contain inclusions of the groundmass. The augite crystals are of light-green colour. This mineral occurs in two generations and possesses octagonal, rounded, prismatic or squarish outlines. In places it occurs as fine needles in aggregated patches. Magnetite is present as inclusions. The groundmass is mostly holocrystalline with very little glass, and consists of small laths of plagioclase felspar with lamellar twinning and minute crystals of augite and magnetite. The felspar in the groundmass is in radiating needles, simulating the imperfect variolitic structure seen in some basalts. Some of the sections are less basic as augite and magnetite are absent from the groundmass, but they occur among the phenocrysts along with olivine.

In the following table is given the chemical analysis of a typical specimen from the Natyindaung, with its molecular proportions and the norm:

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ | 48·16 | 0·802 | Orthoclase | 5·56 |
| $Al_2O_3$ | 15·52 | 0·152 | Albite | 24·10 |
| $Fe_2O_3$ | 6·25 | 0·039 | Anorthite | 26·69 |
| | | | Diopside— | |
| FeO | 4·10 | 0·057 | $CaO.SiO_2$ | 10·67 |
| MgO | 8·22 | 0·205 | $MgO.SiO_2$ | 8·70 |
| CaO | 10·53 | 0·188 | $FeO.SiO_2$ | 0·60 |
| | | | Hypersthene— | |
| $Na_2O$ | 2·84 | 0·046 | $MgO.SiO_2$ | 5·30 |
| $K_2O$ | 0·92 | 0·010 | O.SiO | 0·40 |
| $H_2O+$ | 1·39 | 0·077 | | |
| | | | Olivine— | |
| $H_2O-$ | 0·77 | 0·042 | $2MgO.SiO_2$ | 4·48 |
| $CO_2$ | 0·03 | — | $2FeO.SiO_2$ | 0·34 |
| $TiO_2$ | 0·73 | 0·009 | Magnetite | 9·05 |
| $P_2O_5$ | 0·30 | 0·002 | Ilmenite | 1·37 |
| MnO | 0·16 | 0·002 | Apatite | 0·67 |
| BaO | 0·05 | | | |
| | | | | 97·93 |
| | | | Water | 2·16 |
| Total | 99·97 | | | 100·90 |

## Conclusion.

A large majority of the igneous occurrences of this region indicate that volcanic activity reached its zenith in post-Pliocene times.

The peculiar masses of Hills 1260, 779, 822, Okpo Letpan and Natyindaung, all appear to have been intruded into the country rock, both Peguan and Irrawaddian alike, as sheets or necks. In each case there is little remaining evidence to show the action of the igneous rock upon the soft sands and clays through which it passed, due partly to the rapid rate at which these beds are denuded, but, at the same time, had these intrusives been accompanied by great heat then the beds in contact would have shown some indications of metamorphism. For some reason the metamorphism of the surrounding rocks is very slight and the igneous masses may have been intruded in a plastic condition at low temperatures.

That these masses were intruded after the structural outlines of the Tertiary inliers had been established is definite, and, further, their position appears to have been largely determined by the lines of major faulting along which the majority of the occurrences are found.

The lavas in all cases are very similar, no matter whether the mass occurs wholly in Peguan or in Irrawaddian sands. Natyindaung and Okpo Letpan are definitely post-Irrawaddian in age, indicating that these masses were intruded during the period when the volcanic activity of the region was at its zenith.

Previous to the recent examination of the district by Messrs. E. S. Pinfold and A. E. Day it was thought that pre-Cambrian granites and gneisses were exposed in the vicinity of Salingyi and Shinmadaung, that, in fact, the pre-Tertiary floor was exposed in this region. Their work has definitely shown that this is not the case. Except for the isolated occurrences of granite at Silaung and Minma the majority of the holocrystalline rocks belong to a peculiarly basic suite, and there is small doubt but that they are the hypabyssal representatives of the surface lavas, intruded into the Tertiary rocks at the same time as the volcanic manifestations at the surface.

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WESTERN VIEW OF MOUNT POPA, FROM POPA VILLAGE, SHOWING THE SEMICIRCULAR CRATER AND THE OUTER WALL.

# CHAPTER XXX

## IGNEOUS ACTIVITY (*Contd.*)

## VARIATION IN TIME

## A. MOUNT POPA REGION

Mount Popa, in reality, forms the largest and southernmost of the group of Lower Chindwin volcanoes. Most of the lavas so clearly resemble the types already described from the Chindwin that the same type-names were used in the original description.[1]

The area occupies about 500 square miles and lies between 20° 40′ and 21° 3′ N. lat. and 95° 6′ and 95° 22′ E. long., and is represented on the following one-inch Burma Survey map-sheets, 84 $\frac{0}{4}$, $\frac{0}{\ }$ $\frac{P}{1}$, $\frac{P}{2}$, $\frac{P}{5}$ and $\frac{P}{6}$.

### 1. Physical Geography.

Mount Popa forms a conspicuous landmark in the heart of the dry belt of central Burma. It is in all respects an ideal example of a recently extinct volcano, and it would be difficult to find a volcano more suitable than Mount Popa for text-book illustration (see Plate XV). The main mountain originally had a circular crater, but the whole of the north-western side was blown away, probably by the final paroxysmal outburst, which suggests that the last eruption must have projected its discharge inclined to the sides of the volcano in that direction. The present mountain is, therefore, shaped like a horse-shoe, and it is possible to walk into the crater through the breach in the northern wall. Indeed, cultivation has been carried from the west, the breach is hidden and the mountain presents the conical silhouette characteristic of an ordinary volcano, with concave slopes steepest near the crater rim. The highest points on the

[1] Chhibber, H L., "The Igneous Rocks of the Mount Popa Region," *Trans. Min. Geol. Inst. Ind.*, vol. xxi, 1927, pp. 226-310.

rim are situated on lava flows marking the points where successive flows, welling out of the crater, escaped over it. The highest points are 4,981, 4,801, and 4,501 feet above sea-level, according to the survey maps, and the volcano rises about 3,000 feet from its base (see Plate XVI). The crater wall on the inside is still precipitous in most places—often a sheer cliff with vertical drops up to 1,000 feet.

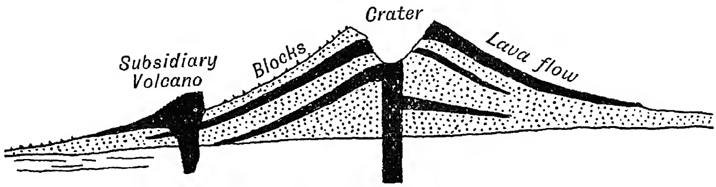


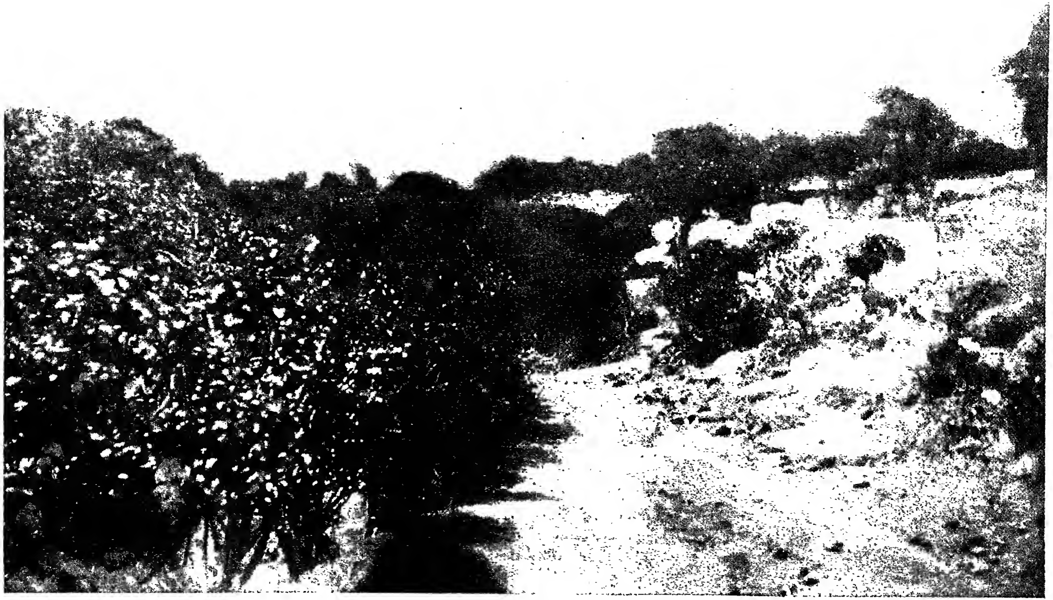

FIG. 24.—Diagrammatic section through Mount Popa.

On the south-western slopes is the extremely precipitous isolated peak known locally as Taunggala, representing the infilled neck or plug of a subsidiary volcano. The main mass of Mount Popa rests on a level plateau, roughly 1,000 feet above the surrounding plains and about 1,800 feet above sea-level. This platform represents the surface-level of the land before the building up of the cone and has been preserved by the resistant capping of lava and tuff (see Plate XX, Fig. 2).

The main mass of Mount Popa should not be confused with the subsidiary ranges of hills to the south and south-west. These hills mark the occurrence of masses of igneous rock of a date earlier than the lavas of the main mountain.

Running south-eastwards from Popa is a range of low, wooded hills extending for some 15 miles, as far as the village of Mogan. The higher points are capped by an older lava and the whole seems to have formed originally a continuous flow. On the south-western side is the Taungni massif of acid tuffs and lavas reaching 1,886 feet above sea-level. Quite separated from the Popa hills are the Kyaukpadaung hills, running in a N.W.-S.E. direction for about 4 miles, with two isolated ridges near Kywelu. These hills were found by Hallowes to be composed of acid tuffs and lavas lying to the south-west of Popa and south of the town of Kyaukpadaung.[1] The small

[1] *Rec. Geol. Surv. Ind.*, vol. xl, p. 109.



THE THREE PEAKS OF MOUNT POPA; FROM NEAR GYAINGYWA VILLAGE, JUST OUTSIDE CRATER. MYINGYAN DISTRICT.

The later ashes and bombs are seen in the foreground on the right.

isolated vent of Taungnauk, which is an auxiliary of the Kyaukpadaung hills, is seen about 2 miles north-east of the town of Kyaukpadaung.

## 2. General Geology of the Region.

It is rather difficult to diagnose the age of two bands of igneous rock unless they are seen in contact. The following table indicates, however, the sequence of the strata in order as far as can be established by field observations.

| | Formation. | Age. |
|---|---|---|
| IX. | Stream Alluvium. | Recent. |
| VIII. | Volcanic detrital Alluvium. | Recent. |
| VII. | The younger Andesites and Basalts with associated Tuffs and Conglomerates. | Largely post-Pliocene. |
| VI. | The interbedded black Tuffs and Ashes. | Pliocene. |
| V. | The Taungni and other partially silicified white Tuffs and Lavas. | Pliocene. |
| IV. | The Kyaukpadaung silicified Tuffs and Lavas. | Pliocene. |
| III. | The Older Andesites and associated Tuffs. | Pliocene. |
| II. | The Irrawaddy Series. | Mio-Pliocene. |
| I. | The Pegu Series. | Oligo-Miocene |

For a detailed account of the Pegu and the Irrawaddian Series of this region reference may be made to the author's paper.[1]

Towards the east of Mount Popa the Pegu Series is exposed, while on the west Irrawaddian sands are seen. The lavas of Mount Popa and other volcanic rocks seem to have been erupted along the Pegu-Irrawaddian junction.

## 3. The Older Andesites and the Associated Tuffs.

The older andesites lying southwards of lat. 20° 53′ N. are much older than the rocks of the present Mount Popa, described as "the younger series." The former exhibit bedding in places and have taken part in the folding movements that characterised the close of the Tertiary period. It is quite probable that the older andesites and the Kyaukpadaung tuffs and lavas are roughly of the same age, though the andesites, as usual, were the first to form, since xenoliths of andesite have been found in the

[1] *Op. cit.*, pp. 235-238.

tuffs and rhyolites of Kyaukpadaung and Taungni. Further, the strike (N.N.W.–S.S.E.) of the two, *i.e.* of the older andesites and of the Kyaukpadaung lavas, coincides remarkably, and they appear to be complementary members of the same magma.

The lower slopes of the hills are often composed of volcanic tuff (conglomeratic in places) overlain by the andesite. Sometimes fragments of Pegu sandstones are enclosed in this clastic rock, and the cement is either calcareous or ferruginous.

This lava, as remarked in the section on geotectonics, has participated in the movement which folded the associated Peguan and Irrawadian rocks. Roughly between lat. 20° 25′ N. and 20° 53′ N. there is a suggestion of anticlinal structure. The eastern limb is quite distinct and much more pronounced than the western, a condition which may be due to faulting.

In places these andesites are characterised by the presence of amygdules filled with pale yellow nail-headed spar which on fracture shows radiating structure. These are very common, especially one mile north-east of Okshitkon village, occurring as veins in the andesite and filling the interspaces.

Near the twelfth milestone on the Kyaukpadaung-Letpanbya road small amygdules of chalcedony are found, which sometimes show a banded and tapering conical structure resembling the form of Burmese pagodas, and hence known as "Pagoda Stones." The bands are alternately white and colourless with a slight bluish tinge. On polishing, the "Pagoda Stones" present an ornamental appearance and are sold as semi-precious stones. They are considered[1] to have originated by the alternate deposition of chalcedony and opal, the former being almost colourless. Some pieces of chalcedony alone are found without any banded structure, while others show an irregular disposition of the white material.

The older andesites as described below comprise the following types:

(1) Pyroxene-andesite.
(2) Augite-hornblende-andesite.
(3) Biotite-pyroxene-andesite.
(4) Pyroxene-andesite with hauyne.
(5) Acid spherulitic andesite.

[1] *Op. cit*, pp. 240-241.

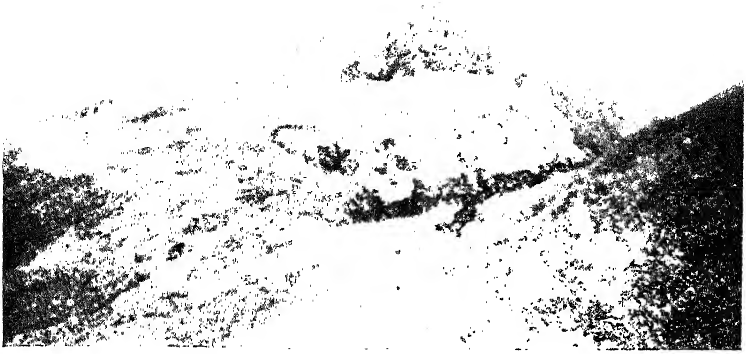


FIG. 1.—SHOWING PART OF CRATER RIM AND THE OUTER SLOPES OF MOUNT POPA.

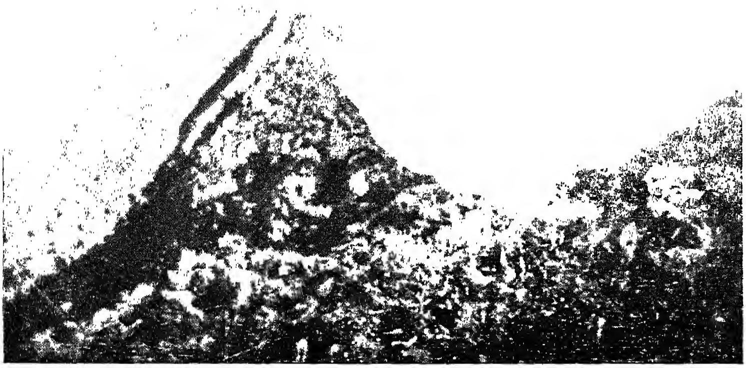


FIG. 2.—SHOWING THE OUTER AND INNER SLOPES OF MOUNT POPA.

**Pyroxene-Andesite.**—The rock outcropping two miles south of Shawdaw, is greyish-black in colour, and phenocrysts of felspar and augite can be recognised with a pocket lens. Its sp. gravity is 2·76. In thin section it shows phenocrysts of felspar, pyroxene, biotite and magnetite. The felspar is quite clear and is andesine approaching labradorite. Some phenocrysts have a clouded interior with a clear margin, or *vice versa*. The pyroxenes include both orthorhombic and monoclinic varieties. The former is enstatite in prismatic plates, with inclusions of magnetite and felspar. Most of the sections are non-pleochroic, but some show slight pleochroism. The monoclinic pyroxene is malacolite. In some sections enstatite is enclosed within the monoclinic pyroxenes. A few altered prismatic plates of biotite are also present in the section.

Magnetite is very profusely distributed throughout the section, with a little haematite staining. The interior of some of the crystals of magnetite has been corroded and filled with pyroxenes. A few pseudomorphs of carbonate are also present.

The hemicrystalline groundmass is of hyalopilitic texture, and consists of small laths of felspar, small granules of pyroxene and magnetite intermixed with a little glass. Some sections of the glassy andesites show perlitic cracks.

An analysis of a specimen of pyroxene-andesite from about two miles south of Shawdaw yielded the following results:[1]

| | |
|---|---|
| $SiO_2$ | 58·10 |
| $FeO$ / $Fe_2O_3$ | 7·20 |
| $Al_2O_3$ | 17·30 |
| $CaO$ | 7·40 |
| $MgO$ | 3·15 |
| [illegible] | 2·22 |
| $K_2O$ - - | 1·62 |
| $MnO$ - - | 0·25 |
| $SnO_2$ - - | 0·30 |
| Loss on ignition | 1·90 |
| Total - | 99·44 |

In some sections hornblende, while in others hypersthene, is present in addition to the minerals described above.

[1] By Messrs. D. Waldie & Co., Calcutta.

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| $SnO_2$ | 0·30 |
| Loss on ignition | 1·90 |
| Total | 99·44 |

In some sections hornblende, while in others hypersthene, is present in addition to the minerals described above.

[1] By Messrs. D. Waldie & Co., Calcutta.

In places both the phenocrysts and the groundmass have changed mainly to haematite and calcite. Irregular pseudomorphs of calcite are numerous and an irregular banded structure is often noticed. In places the whole of the felspar crystal is replaced by calcite; in others calcite either fills the interior or occupies the outer border. Commonly the pyroxenes have changed to serpentine. Sometimes the rock shows several irregular geodes filled with zeolites and lined with haematite.

In places these andesites have undergone silicification, when pseudomorphs of chalcedony, after the ferro-magnesian minerals and the felspars, are visible. The change is not confined to the phenocrysts but affects the groundmass also, as the latter contains many irregular patches of chalcedony distributed through it. In some places the pyroxene-andesites carry hauyne.

**Acid Spherulitic Andesite.**—The rock from half-a-mile east of Kyauktaga from the axis of the ridge contains clear phenocrysts of felspar. The ferro-magnesian minerals have largely altered to serpentine with only a few pieces of unaltered enstatite remaining. The groundmass shows a spherulitic structure which has developed round either a crystal of magnetite or of felspar. The radiating structure consists of crystallites, or in some cases of microlites of felspar. It is noteworthy that the rock is rather acidic as there are fewer dark minerals.

The older andesites are in places injected with veins of a pale-yellowish rock with dull greasy lustre, and breaking with a conchoidal fracture. A good example occurs about 2 miles S.S.E. of Shawdaw. Under the microscope the thin section is seen to consist of two minerals only. There are abundant rounded grains of a brownish isotropic garnet; the matrix is colourless, water-clear, and under crossed nicols has the characteristic brush polarisation effects of scapolite. It would seem that these veins of garnet-scapolite rock have been formed in cracks during a late stage in the volcanic activity of the region. In another specimen, from 2½ miles S.S.E. of Shawdaw on the western flank of " 1946," garnet is absent, its place being taken by what appears to be limonite.

### 4. Gwegon Andesites.

Similar, but highly silicified older andesites exist south of the village of Gwegon and west of Konde. There are three isolated outcrops of this rock surrounded by partially silicified white tuffs, one near the Pagoda " 1145," the second marked " 1159," and the third immediately to the south of it. The strike of the rocks coincides with the strike of the main mass of the older andesites and the two may have been contemporaneous in eruption; but it seems likely that this area marks a separate focus of volcanic disturbance and the height of the vents has been lowered by denudation. These rocks consist mainly of pyroxene-biotite-andesites and biotite-andesites, but their striking character is their silicification, a condition brought about by gases and vapours, which also silicified the neighbouring tuffs.

Under the microscope the rock, from north of the Pagoda, south of Gwegon village, is seen to consist of phenocrysts of felspar and biotite, both of which are altered in places. The former contains glass inclusions. Some of the phenocrysts of felspar are replaced by chalcedony or opal, with its characteristic banded structure and sometimes with a kernel of crystalline silica. In some cases the change has proceeded from the outside, leaving a kernel of zoned felspar unaffected, while in others the interior has been entirely changed, leaving the border unaltered. The groundmass has become clouded and appears whitish by reflected light with a few scattered laths of felspar and biotite. It appears that the siliceous, thermal solutions which wrought the partial silicification of the white tuffs, and which also helped in the formation of opaline fossil wood, were instrumental in bringing about this change in the andesites. The yellowish irregular banding seems to be due to the diffusion of ferruginous solutions in the siliceous gels, quite similar to that seen in agates, but on a microscopic scale. Sometimes the crystalline silica filling in the kernels shows an imperfect spherulitic structure. Some well-developed crystals of magnetite are also seen. The groundmass is typically glassy, with a few minute specks of felspar here and there.

The thin section of a specimen from a little north of the

pagoda near Gwegon shows similar characters, with the difference that some of the prismatic and hexagonal sections of biotite have been corroded and filled with magnetite in the same way as the hornblende in the younger andesites.

Some specimens contain pyroxenes in addition to the minerals described above. They include both orthorhombic and monoclinic species, generally altered to serpentine, and some of the phenocrysts of felspar are corroded and are filled either with serpentine or glass, in the latter case developing the "corona" structure. In some rocks phenocrysts of augite have also been replaced by chalcedony.

The groundmass is hemicrystalline, and consists of small laths of felspar and granules of augite and magnetite.

It appears that the Gwegon andesites are intermediate between the basic andesites towards the east and the acidic andesites on the west, and hence afford an admirable illustration of differentiation of magma in the case of extrusive lavas.

### 5. The Kyaukpadaung Silicified Tuffs and Lavas.

The Kyaukpadaung hills extend roughly in a N.W.–S.E. direction and are composed of silicified tuffs with interbedded lava sheets. The latter include rhyolites and andesites. The main hills are continuous for four miles and end about one mile north-west of Sanzu. The other two occurrences, however, in the same line, start about one mile south of where the main hills end and terminate about half a mile south of Kywelu village. About two miles north-west of the twin hills of Kyaukpadaung is the isolated vent of Taungnauk, which has roughly an E.–W. strike. These pyroclastic rocks are wholly silicified, and are very hard, compact and fine-textured. In places they show bedding and jointing as seen near the Pagoda, "1886." The shade of the rocks is variable and the specimens are cream-coloured, light pink, yellowish, greyish, reddish or whitish. Some of the specimens of fine-grained siliceous rocks belonging to this series have all the physical and mineralogical characters of chert.

The rhyolite consists of felspar and quartz, sometimes with augite. The felspar is largely altered and of a pale grey colour.

THE TWIN VENTS OF KYAUKPADAUNG, COMPOSED OF RHYOLITE AND RHYOLITE TUFFS. MYINGYAN DISTRICT.

The growth of quartz seems to be secondary, as its colourless patches exhibit irregular bands of a pale yellow colour similar to those seen in onyx, probably due to the diffusion of iron salts, which also can be seen megascopically lining the cavities. This production of a banded structure on a microscopic scale appears to be a case of the " Liesegang phenomena."

The rhyolite tuffs consist of irregular fragments of quartz and felspar. Both these minerals are quite clear and colourless and in places traversed by cracks. In some cases the outline is triangular, and some of the patches of quartz, when observed under crossed nicols, resolve themselves into microcrystalline aggregates.

The groundmass consists largely of glass in which minute fragments of quartz are interspersed. A large proportion of the groundmass consists of haematite, which may be secondary. In some sections a little foliated muscovite is seen, and the quartz fragments are full of glassy inclusions. Pieces of rhyolite consisting of a fine granular mosaic of quartz and felspar often occur. A few fragments of felspar are also to be seen ; these are cemented by glassy opaque material which appears whitish by reflected light.

A thin section shows large prismatic phenocrysts of felspar which are set in a matrix of quartz and felspar. Sometimes the quartz and felspar in transmitted light are quite clear, but on crossing the nicols some of the felspar appears opaque owing to silicification.

### 6. The Taungnauk Rhyolites and Tuffs.

The isolated Taungnauk hill also, as remarked above, is composed of rhyolites and silicified tuffs. It shows that contemporaneous volcanic eruption took place at different places, and the two vents near Kywelu afford another striking instance of this fact. Some of the specimens of rhyolites show flow structure and vesicular texture. Disseminated through some of the vesicles are haematite, psilomelane and carbonates.

**Biotite-Andesites.**—The biotite-andesites described below occur either close to the Kyaukpadaung Hills or interbedded in them. They appear to represent acidic segregations of the

magma from which the older andesites described above were formed, but as they are very close to the Kyaukpadaung lavas they are described with them. The four well-marked occurrences of these lavas are on or close to the Kyaukpadaung-Magyigon road. The first one is near the fourth milestone marked on the map. The second is near the fifth milestone, "1145," near the Pagoda of the village of Wetkyikan. The third is W.S.W. of the village of Thabyebyo at the Pagoda "1007." The last is interbedded with tuffs about $\frac{3}{4}$ mile S.W. of Inbin village. In the second occurrence easterly dips of 68° are clearly observed. Biotite appears to be almost a constant constituent of these andesites. The following types are found among these rocks:

(1) biotite-augite-andesite, (2) biotite-augite-hornblende-andesite, (3) hornblende-andesite, and (4) biotite-andesite.

Under the microscope a thin section of biotite-augite-andesite shows phenocrysts of felspar—including both orthoclase and plagioclase—and of biotite. The felspar phenocrysts are mostly idiomorphic and contain inclusions of glass, while the plagioclase felspars include both andesine and labradorite. The biotite is brown and shows reaction rims, whilst inclusions of felspar crystals are quite common. As a result of alteration it has yielded vermicular chlorite or serpentine; sometimes these minerals fill the felspar. A few phenocrysts of light-green augite are also present and are sometimes pseudomorphed by calcite. Fragments of rock, inset in the section, chiefly consist of zoned plagioclase felspar.

The hemicrystalline groundmass is very fine textured and is pale-grey in colour, appearing whitish by reflected light; it consists of minute laths of felspar set in a glassy matrix. There is a well-marked tendency towards perlitic cracks in the groundmass. In some sections the groundmass is entirely glassy.

A specimen of the biotite-hornblende-augite-andesite contains definite phenocrysts of hornblende, besides the minerals enumerated above. Occasional prismatic sections show slight pleochroism and the interference tints and straight extinction of hypersthene or ferriferous enstatite.

An interesting specimen of biotite-andesite comes from the eastern flank of the Kyaukpadaung hills one-and-a-quarter miles south-east of Wetkyikan. The rock is well-bedded, shows

excellent flow structure, and is associated with the silicified tuffs of the Kyaukpadaung hills. It is light-grey in colour with a pinkish tinge. The weathered surface presents an etched appearance. The rock contains phenocrysts of felspar and biotite. The felspar shows zoning, but lamellar twinning is almost absent. The crystals have been corroded and filled with groundmass; in places they are partially altered to calcite. The biotite possesses the usual characters; in places it has altered to some dark opaque material and in others to calcite. A few well-built crystals of magnetite are also noticeable. On the whole the grain of the rock is fine.

The groundmass is rather trachytic in nature and consists of small laths of felspar with square or short prismatic outlines, but it is very decomposed and full of large irregular patches of calcite.

A chemical analysis[1] of the rock yielded the following results:

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ | 64·46 | 1·074 | Quartz | 18·06 |
| $Al_2O_3$ | 17·48 | 0·175 | Orthoclase | 21·68 |
| $Fe_2O_3$ | 2·93 | 0·018 | Albite | 35·11 |
| $FeO$ | 0·53 | 0·007 | Anorthite | 16·12 |
| $MgO$ | 0·85 | 0·021 | Corundum | 1·12 |
| $CaO$ | 3·61 | 0·064 | Enstatite | 2·10 |
| $Na_2O$ | 4·15 | 0·067 | ($MgO.SiO_2$) | |
| $K_2O$ | 3·70 | 0·039 | Magnetite | 0·93 |
| $H_2O+$ | 1·72 | 0·095 | Haematite | 2·24 |
| $H_2O-$ | 0·17 | 0·009 | Ilmenite | 0·46 |
| $CO_2$ | — | — | Apatite | 0·67 |
| $TiO_2$ | 0·26 | 0·003 | | |
| $P_2O_5$ | 0·33 | 0·002 | | 98·49 |
| $MnO$ | 0·03 | — | Water | 1·89 |
| $BaO$ | 0·12 | 0·001 | | |
| | 100·34 | | | 100·38 |

**Alteration.**—Sometimes the phenocrysts of felspar have been entirely altered and are isotropic between crossed nicols. They have probably undergone silicification or zeolitisation, a common change noticed in other lavas of this series. Here and there traces of original felspar have been left: in some cases the interior has been entirely silicified, while a thin border is

[1] By T. Marrack, A.R.S.M., M.Sc.

clear, but in others the opposite change is to be noticed and in certain cases such an appearance simulates nosean. The felspar in the groundmass has undergone the same change. In some cases octagonal pseudomorphs after augite are to be observed.

**Age.**—As regards the age of these silicified tuffs and interbedded sheets of acid lava it appears certain that they are older than the younger lavas of Mount Popa. At the same time these acidic extrusions were formed subsequently to the older andesites. In places the two are intermixed, as, for example, towards the east of Mongan and Okshitkon villages. It may, therefore, be said that the older andesites and the acid lavas of the Kyaukpadaung hills, etc., were formed as a result of the differentiation of the same magma, the latter having been erupted through the former in places, but belonging to the same period of igneous activity. It is true that the Kyaukpadaung volcanoes are older than that of Mount Popa, which marks the latest flow that was erupted most probably after the deposition of the Irrawaddian. The Kyaukpadaung lavas were erupted while the deposition of the Irrawadians was still in progress, as some of the tuffs are clearly interbedded with Irrawaddian rocks.

### 7. The Taungni, Gwegon and Sebauk Tuffs.

The tuffs described below differ from those described in the previous section in that the main rock is a coarse whitish tuff, partially, or in places, completely silicified. Hard and compact specimens resembling the tuffs of the previous section are associated with these rocks. The rock is so white as to resemble a deposit of chalk or calcareous tufa. It is bedded and in places has been thrown into anticlinal folds, which are seen towards the north-east and north of Sebauk village. In Taungni hill there is a suggestion of anticlinal structure ; the direction of the anticlinal axes is N.N.W.–S.S.E.

The typical occurrences of the rock are those of the Taungni massif, which appears to be a tuff cone. Its northerly extensions are seen near the villages of Kyaukkon, west of Konde, and east and south of Gwegon. Other similar occurrences are seen

towards the north and north-east of Sebauk village and extend as far north as the west of Taunggala, "2417." It will be seen that it accompanies andesite up to the limit of the outcrop; the two are intermixed in places. The siliceous tuffs become agglomeratic elsewhere.

**Taungni Hill.**—The rocks of Taungni Hill consist of both silicified and unsilicified tuffs, the former displaying a variety of colours, the latter a cream to white tint. In the cavities of the silicified tuffs well-developed colourless crystals of quartz are sometimes seen. The hard, silicified, fine-grained rocks occasionally show coloured rhythmic banding of iron oxide owing to the diffusion of the iron salts through these crypto-crystalline siliceous rocks—another case of the Liesegang phenomena.[1] The older andesites are also seen on the southern slopes of this hill, where they occupy a lower position; being extrusive rocks they must be older than the overlying white tuffs. This fact was further confirmed by the finding of specimens of rhyolites (and allied tuffs) containing xenoliths of andesite. Further, weathered fragments of andesite are enclosed in the white tuffs.

The second main occurrence of these white tuffs is to the east and south of Gwegon village. They do not call for any special mention. Specimens of red and variegated jaspers are associated with them.

The third notable occurrence of the tuffs is to the north and north-east of the village of Sebauk. The tuffs, as usual, are white, friable and present a chalky appearance. The rock is well bedded, and north of Sebauk shows south-westerly dips where it caps the Irrawaddy Series and exhibits pot holes in the stream channels. About half a mile north of Sebauk it presents a steep scarp. The Irrawaddy sandstone forms the lower portion overlain by tuff; the steepness of the scarp is due to the more resistant covering of tuff preserving the underlying soft sand-rock which has been removed from the neighbourhood. Another occurrence is in the valley about one mile west of Taunggala, where chalky white tuff is interbedded with Irrawaddian sands.

[1] Chhibber, H. L., "Rhythmic Banding in Silicified Tuffs," *Geol. Mag.*, vol. lxiv, 1927, pp. 7-9.

The rock is friable, chalky white in colour with a coarse texture. Scattered through the white mass altered pieces of rhyolite, andesite and ferro-magnesian minerals like biotite and augite are seen. The white groundmass seems to be largely altered felspathic material, partly replaced by opaline silica. This fact is confirmed under the microscope, as thin sections show clear pieces of unaltered felspar. The alteration appears to have been largely brought about by the same gases, vapours and thermal waters which have been instrumental in altering other rocks in this area.

A white tuff from east of Gwegon village consists of an aggregate of crystals of felspar, altered pieces of pumice, biotite and magnetite. The pieces of pumice show a fibrous structure and are isotropic under crossed nicols. The felspar fragments show zoning and appear to have been derived largely from the andesites. Sometimes the interior of a crystal has been corroded and is filled with dusty opaque material which appears to be opaline silica ; part of the white material may be kaolin, formed by the alteration of felspar. All these are set in a dusty opaque material, the nature of which is the same as that described above. Clear pieces of secondary quartz are also present.

Sometimes unsilicified tuffs are also seen towards the southern portion of the area, and are generally characterised by a ferruginous matrix. They are generally of a speckled red or yellow colour. Occasionally pieces of Peguan shales and sandstones are enclosed in them.

These tuffs are silicified in places, and then comprise types like silicified rhyolite. A specimen of silicified greyish-black tuff is not unlike flint, with a sub-conchoidal fracture.

A thin section of the silicified tuffs is remarkable, however, for black or brownish patches visible under the microscope. In places what appear to be crystals of felspar or biotite have assumed this black colour, but under crossed nicols some show a microcrystalline mosaic of silica, while others are quite opaque. Similar patches have been mentioned by Rutley ; [1] Dr. Hinde, who examined Rutley's specimens, concluded that the black colour was due to organic material. It is quite probable that

[1] Rutley, F., *Q.J.G.S.*, vol. 58, 1902, p. 13.

the black colour in this case may be due to carbonaceous material derived from the Peguan rocks ; or it may be due to manganese salts, as seen in some jaspers. Scattered through this blackish material are colourless patches of silica with banded margins, and these in places resolve themselves into radiating spherulitic aggregates between crossed nicols.

**Biotite-Hornblende-Gneiss.**—The rock from the hill east of Okshitkon village appears to be a biotite-hornblende-gneiss, and was found associated with andesite and other tuffs. Under the microscope a thin section consists of a granular aggregate of quartz and felspar with streaks of biotite and hornblende and a little magnetite. A little apatite also appears to be present and some silica seems to have been introduced subsequently. In places a micrographic structure is suggested. The specimens of these gneisses and mica-schists associated with white tuffs, described below, show that the latter have undergone metamorphism, largely of a thermal character ; this was brought about by subsequent volcanic discharges, heated gases and vapours, aided by regional metamorphism due to earth-movements which occurred at the close of the Tertiary period.

**Mica-schist.**—A specimen of a mica-schist from two miles due south of Taunggala, associated with white tuff near Sebauk, is light-grey in colour and consists of muscovite and quartz. Under the microscope a thin section shows a granular mosaic of quartz and colourless flakes of muscovite. Most probably this schist was formed by earth-movements which folded the white partially silicified tuffs. Similar metamorphism of fine tuffs into silky schists has also been recorded by Geikie.[1]

**Age.**—These rocks appear to be older than the lavas of Mount Popa. They are interbedded with Tertiary sands west of Konde village. A thin covering of the Irrawaddian is seen capping them ; they seem therefore contemporaneous with the closing of the Irrawaddian epoch (Pliocene period). Further, these white tuffs are older than the interbedded black tuffs, as they occupy a lower position in the Irrawaddian sands and have undoubtedly taken part in the folding movements, while the black tuffs are almost horizontal. But the white tuff is younger than the older flow of andesite and the Kyaukpadaung

[1] Geikie, A., *Q.J.G.S.*, vol. lviii, 1883, p. 301.

lavas, as fragments derived by denudation from the former rocks partake in the formation of the white tuff.

### 8. The Interbedded Black Tuffs and Ashes.

The Black Tuffs and Ashes are exposed all round the slopes, especially on the west, of the plateau on which Popa stands, interbedded with the Irrawaddian rocks of which the plateau is built. The rock is generally a coarse-grained ash which often passes into coarse tuffs where the pieces of andesitic rocks have been cemented by finer ash. With these, similar black basal tuffs underlying the lavas of Mount Popa may also be included as they are not very different petrographically. The ash is usually a stratified deposit, and its best sections are seen near Sinzin village and at the pagoda point about two miles to the west (see Plate XIX, Fig. 1). Here the almost horizontal bedding is so fine and regular that steps leading to the pagoda have been cut out of these rocks. Similar beds, over which the younger andesite has flowed, crop out opposite the pagoda.

Sometimes these rocks are intercalated in the Irrawaddian sands, but in places they cap the latter. It is probable that in this case the upper covering has been denuded away, or was not laid down at all.

These rocks, like the older white tuffs, are interesting in that they furnish evidence regarding the date of commencement of the volcanic activity round Mount Popa itself. The rocks are interbedded with the upper Irrawaddian, suggesting thereby that the Popa volcano was first active towards the close of the Pliocene period. Sir Edwin Pascoe notes that " activity commenced in Irrawaddian times, but the later and larger flows of augite- and hornblende-andesite and the clastic material derived therefrom were in all probability post-Irrawaddian." [1]

These interbedded rocks consist largely of soft ash grading into black basaltic or andesitic tuff which consists of pieces of lava cemented by the softer ashes.

**Andesitic Tuff.**—The rock outcropping opposite the pagoda, about two miles west of Sinzin village, is grey in colour, and dark-green pyroxene and clear felspar can be recognised with

[1] *Mem. Geol. Surv. Ind.*, vol. xl, p. 45.

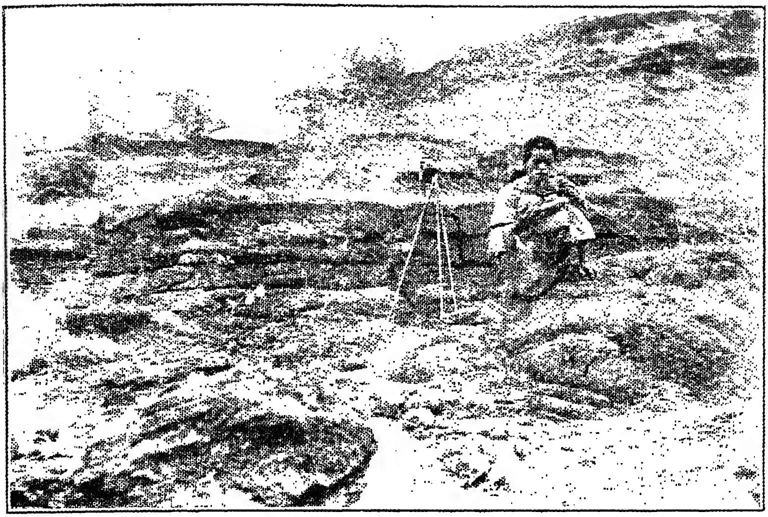

FIG. 1.—VOLCANIC ASH AND TUFF BEDS AT THE PAGODA, TWO MILES WEST OF SINZIN VILLAGE. MOUNT POPA AREA, MYINGYAN DISTRICT.


G. 2.—THE INTRUSION OF DOLERITE INTO THE PEGU SERIES, "THREE FALLS HILL," ZIGON AREA, THARRAWADDY DISTRICT.

the pocket lens. Under the microscope a thin section consists of laths of felspar and pyroxenes (see below).

The rock, from about $1\frac{1}{2}$ miles S.S.W. of Popaywa village, taken from the outer edge of the plateau, is soft and grey-coloured with pieces of andesite enclosed in it. The thin section is remarkable for its large crystals of brown hornblende showing reaction rims, with augite and clear felspar set in a glassy matrix.

**The Volcanic Ash** is of a light-grey colour and is soft and fine-grained. Under the microscope it appears to consist of very minute laths of felspar and fine granules of pyroxene cemented by dark glass. It is possible that the specimens represent consolidated volcanic dust.

## 9. The Younger Andesites and Basalts, with Associated Tuffs and Conglomerates.

The andesitic lavas of the Mount Popa area north of lat. 20° 53′ and extending up to the village of Legyi (near Seiktein, which marks the northernmost limit of lava), appear younger than the andesites described above. In the field the younger andesites are generally distinguished by well-developed squarish phenocrysts of dark-green augite and sometimes of brownish-black hornblende, although in places these phenocrysts are not so well marked. The rock is of grey, greenish-grey or greyish-blue colour. It is remarkable that besides undisturbed flows, piles of disintegrated boulders of lava are strewn all round Mount Popa north of the latitude given above. Wherever lava has flowed down steep slopes it has generally split up into blocks, and this is best seen on the slopes of the plateau surrounding Mount Popa. Sometimes these blocks are clearly resting on the Tertiary sands. These small accumulations of broken boulders represent disintegrated flows, and the upper surface of the boulders often shows signs of having come from the surface of a flow, exhibiting a ropy and slaggy appearance.

In the centre there is the enormous mass of Mount Popa itself, mostly a tuff and lava cone, rising at least 3,000 feet above the plateau on which it stands. Sir Edwin Pascoe notes that what

is left of the crater wall is formed of breccia or agglomerate.[1] In the crater we find good exposures of agglomerate to which we may give the name of "crater agglomerate." This deposit is best seen in the streams near the villages of Taungbaw, Gyaingywa, Kanzatkon, etc. The top of the main mountain

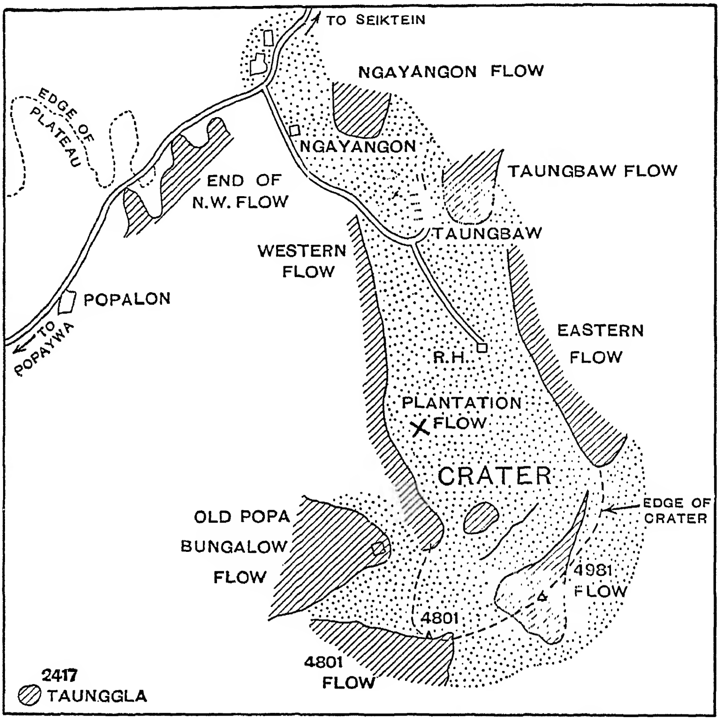


FIG. 25.—Sketch-map showing the position of the separate lava flows of Mount Popa. The dotted areas represent tuff and agglomerate. Scale, 1″ = 1 mile.

is covered with layers of volcanic ashes, tuffs, cinders, bombs, etc., of varying thickness, approaching 100 feet or more in places.

The bedding in the lava is most clearly visible in the crater (see Plate XX) and may vary from approximately 20° to 30°. The dip is quaquaversal, as is to be expected in lava poured out in all directions from a central orifice.

[1] *Rec. Geol. Surv. Ind.*, vol. xl, p. 109.

PLATE XX.

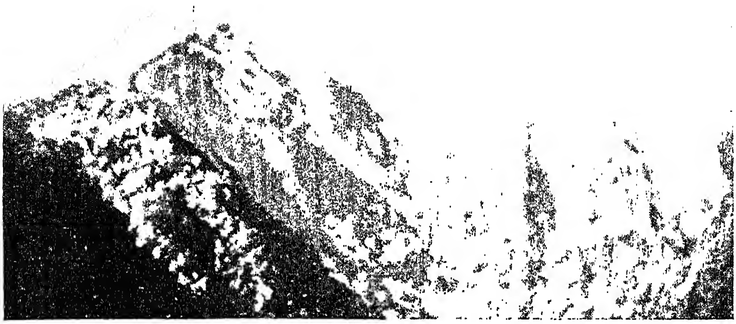

FIG. 1.—THE INNER SLOPES OF MOUNT POPA, ILLUSTRATING BEDDING IN SOME OF THE LAVA FLOWS.

FIG. 2.—RAISED PLATEAU ROUND MOUNT POPA WITH AN OUTLIER OF VOLCANIC TUFF ON THE RIGHT.

Volcanic conglomerate and tuffs are sometimes associated with these andesites, and in places extend far into the slopes of Mount Popa. The cuttings made by streams expose small and large fragments of andesite cemented by ash or other volcanic detritus. Often the place of these subangular pieces is taken by big boulders when they constitute volcanic boulder beds. This stratified deposit was laid down by the streams issuing from near the top of the mountain. Water was probably supplied to these streams by the torrential rains caused by the condensation of the steam which usually accompanies volcanic eruptions. The streams mostly deposited the material blown out by the volcano : ashes, lapilli, bombs, etc., together with disintegrated lava boulders. The study of the relations of this deposit to the overlying andesite in places points to the volcanic eruptions being paroxysmal. This supposition is further supported by the recognition of several distinct flows in the area, which it is possible to distinguish and map, and there is a considerable variation in petrographic characters between neighbouring ones. Fig. 25 shows some of the more important flows round the crater, and the following table indicates their petrographic characters :

| | |
|---|---|
| Taungbaw flow. | Acid olivine-basalt.[1] |
| Ngayangon flow. | Hornblende-augite-andesite. |
| Old Popa Bungalow flow. | Hornblende-augite-andesite. |
| "4,801" flow. | Glassy hypersthene-augite-andesite. |
| Western flow. | Olivine-basalt. |
| Eastern flow, best seen below the △ marked on the one-inch sheet. | Olivine-basalt ; hornblende-augite-andesite, etc. |
| North-western outer flow. | Hornblende-augite-basalt. |
| Plantation flow. | Enstatite-basalt. |
| Western crater wall flows. The western crater wall is mostly steep, and sometimes a sheer cliff. In places as many as ten flows can be counted. | Hornblende-augite-andesites. |

A number of bedded flows are seen in the crater walls; this is particularly the case in the eastern wall. During a

[1] These basalts are slightly more acidic in composition than their normal representatives.

subsequent visit the author observed a number of distinctly bedded flows below Δ marked N.N.E. of 4981. The average thickness of the flows is roughly ten feet. The walls are so precipitous that it is difficult to map some of them separately on the available one-inch maps.

### The Taunggala Type. Hornblende-Augite-Andesite.

The hill known as Taunggala, "2,417," forms a remarkable feature on the south-western slopes of Mount Popa; in section it is roughly circular and rises precipitously on all sides. It consists of a plug of igneous rock intruded into Irrawadian sands, which, in general, dip away from the igneous mass. Taunggala is a typical subsidiary neck on the flanks of the main volcano.

The rock is dull-grey in colour, often with a purplish tinge due to weathering, and is characterised by elongated crystals of hornblende. It has a coarser and more even-grained texture than most of the igneous rocks of this area. It is possible to distinguish large lustrous crystals of augite, others of hornblende, duller and rather brownish in tinge, and small red crystals and whitish patches of felspar. Some parts of the rock are coarser than others. Its specific gravity is 2·74.

The most abundant phenocrysts in this rock are pseudomorphs which, from their general shape and character, appear to be after hornblende. In certain cases a greenish-brown pleochroic hornblende is still the principal mineral in the centre of the phenocrysts, but in the majority, the original hornblende has been replaced by a remarkable granular aggregate of minerals. The pseudomorphs are outlined by a broad dusty border. The principal minerals in the aggregate are augite, felspar, magnetite and biotite. The phenocrysts of pale green pyroxene appear to be malacolite, as the extinction angle does not exceed 38°; they do not differ markedly from those seen in the majority of the recent lavas. They are obviously later than the hornblende phenocrysts, for large augite phenocrysts are often seen penetrating the disrupted hornblendes. There are numerous phenocrysts of felspar, some very large,

but for the most part smaller than the other phenocrysts. Nearly all the felspars are zoned and they are mostly plagioclase. It would seem that there was an early crop of felspar phenocrysts, consisting mainly of orthoclase or acid plagioclase which suffered disruption and corrosion, followed by regrowth at a later stage by the addition of zones of a more basic plagioclase, not always deposited in crystallographic continuity, but filling up irregular corrosion cavities. The extinction angles measured on albite lamellae do not exceed those of andesine-labradorite.

The groundmass is holocrystalline and consists of felspar laths with abundant granules of augite and magnetite.

It appears certain that the magma was supersaturated with hornblende—as evidenced by many long pseudomorphs. Consequently hornblende was the first mineral to form ; it was then reacted upon by the residual magma, resulting in corrosion of the hornblende crystals and their consequent filling with augite crystals or groundmass.[1]

In some cases the corroded crystals have served as nuclei round which augite crystals have developed ; hence the supersaturation of magma with hornblende is proved. Some are seen partly filled with felspar, augite and groundmass. In other sections felspar and augite show ophitic or subophitic relations, and there is evidence to prove that in some cases the crystallisation of augite and felspar proceeded simultaneously.

In some sections the felspar has been altered to a pale yellow or pale pink mineral which is isotropic and may be analcite. Islands of unaltered felspar are often to be seen. It is quite possible that the alteration of felspar to analcite, both in the phenocrysts and groundmass, and the development of the greenish tinge in the hornblende have been brought about by the escaping gases and vapours which are generally emitted during the waning phases of an eruption. Associated with the magnetite is some primary haematite, orange-red in colour. It is also seen as inclusions in hornblende and other minerals. Crystals of specular iron ore are found associated with these rocks and are locally called Popa "*sein*," or Popa "diamonds."

[1] Teall, J. J. H., *British Petrography*, p. 260.

A typical specimen from the neck of Taunggala on analysis [1] yielded the following results.

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ | 49·07 | 0·817 | Orthoclase | 11·12 |
| $Al_2O_3$ | 17·11 | 0·168 | Albite | 23·06 |
| $Fe_2O_3$ | 5·10 | 0·031 | Anorthite | 28·91 |
| | | | Diopside— | |
| $FeO$ | 3·29 | 0·048 | $CaO.SiO_2$ | 8·70 |
| $MgO$ | 6·43 | 0·160 | $MgO.SiO_2$ | 7·05 |
| $CaO$ | 10·72 | 0·190 | $FeO.SiO_2$ | 0·60 |
| | | | Hypersthene— | |
| $Na_2O$ | 2·79 | 0·044 | $MgO.SiO_2$ | 5·08 |
| $K_2O$ | 1·95 | 0·020 | $FeO.SiO_2$ | 0·42 |
| | | | Olivine— | |
| $H_2O+$ | 1·68 | 0·093 | $2MgO.SiO_2$ | 2·80 |
| $H_2O-$ | 0·81 | 0·044 | $2FeO.SiO_2$ | 0·24 |
| $P_2O_5$ | 0·45 | 0·003 | Magnetite | 7·19 |
| $TiO_2$ | 0·52 | 0·006 | Ilmenite | 0·91 |
| $CO_2$ | 0·17 | 0·003 | Apatite | 1·01 |
| $MnO$ | 0·18 | 0·002 | Calcite | 0·30 |
| $BaO$ | 0·08 | 0·001 | | |
| | | | | 97·39 |
| | | | Water | 2·49 |
| Total | 100·35 | | Total | 99·88 |

## The Taungbaw Flow.

**Acid Olivine-Basalt.**—This type is from one of the minor flows of the present Mount Popa and is found to the north of the crater where the wall has been entirely blown away. It is probable that the flow was originally far more extensive and that the greater part was destroyed by the final disruption of the mountain ; the mass now remaining forms a small hill immediately to the east of Taungbaw village.

The rock is purplish-grey in colour, with numerous small phenocrysts of dark-green augite and abundant small, reddish-brown phenocrysts which form a distinctive feature of the freshly broken surface.

This rock contains a few of the phenocrysts, apparently pseudomorphous after hornblende, which were described in

[1] Analysis by T. Marrack, A.R.S.M., M.Sc.

connection with the rock of the Taunggala neck. The most numerous phenocrysts are of pale-greenish augite (malacolite), usually showing good crystal forms with inclusions of magnetite and haematite. Some of the sections show beautiful zoning. The phenocrysts of felspar are numerous, zoning is less marked than in most of the Popa lavas, and there is every gradation from large phenocrysts to the small crystals of the groundmass. An acid labradorite seems to be the dominant felspar. A feature of particular interest is the occurrence of a few small phenocrysts of olivine of irregular outline. The characteristic cracks are observed, with deposition of a red mineral (probably haematite) along them.

The groundmass is holocrystalline, and consists of small lath-shaped felspars, granules of augite and magnetite. This rock is really intermediate between an olivine-andesite and an ordinary basalt. In a rock from half a mile south of Taungbaw vesuvianite was observed in addition to the normal minerals in basalt.

### The Ngayangon Flow.

**Hornblende-Augite-Andesite.**—Like the Taungbaw type this comes from one of the minor flows of the present Mount Popa, and is also found to the north of the crater where the greater part of the flow was probably destroyed in the final disruption of the mountain. The remnant forms a small hill just to the east of the village of Ngayangon. A similar rock was observed north of Kanzatkon village.

This lava is a fine-grained rock with a whitish and purplish mottled appearance, the mottling being on a fine scale. There are numerous small phenocrysts of black or reddish-brown colour.

This rock is very similar to the one from the Taungbaw flow. Many of the hornblende phenocrysts have not, however, been completely replaced, and consist of a bright brown hornblende, very strongly pleochroic, of the basaltic hornblende type. Associated with the hornblende crystals are a few flakes of biotite. The felspar, both as phenocrysts and in the groundmass, is partly corroded and filled with small specks of calcite. Some of the crystals of augite and felspar show

"glomeroporphyritic" texture. No olivine was seen in this rock.

A chemical analysis[1] of a typical specimen revealed the following chemical composition:

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ | 54·21 | 0·903 | Quartz | 6·84 |
| $Al_2O_3$ | 18·48 | 0·180 | Orthoclase | 14·46 |
| $Fe_2O_3$ | 6·06 | 0·038 | Albite | 24·63 |
| FeO | 1·16 | 0·016 | Anorthite | 29·75 |
| | | | Diopside— | |
| MgO | 4·02 | 0·100 | $CaO.SiO_2$ | 3·60 |
| CaO | 8·08 | 0·144 | $MgO.SiO_2$ | 10·00 |
| $Na_2O$ | 2·98 | 0·047 | Magnetite | 2·32 |
| $K_2O$ | 2·44 | 0·026 | Haematite | 4·48 |
| $H_2O+$ | 1·21 | 0·067 | Ilmenite | 1·06 |
| $H_2O-$ | 0·44 | 0·024 | Apatite | 0·67 |
| $CO_2$ | — | — | | |
| $TiO_2$ | 0·58 | 0·007 | | |
| $P_2O_5$ | 0·33 | 0·002 | | 97·81 |
| MnO | 0·13 | 0·001 | Water | 1·65 |
| BaO | 0·14 | 0·001 | | |
| Total | 100·26 | | | 99·46 |

## The Old Popa Bungalow Flow.

**Hornblende-Augite-Andesite.**—This flow occurs on the western flank of the main mountain about 500 yards down from the crater wall. The specific gravity of the rock is 2·48. The silica percentage of the rock as determined by Messrs. D. Waldie & Co., Calcutta, is 59·9 per cent.

It is a pale-grey, rough-textured rock in which small white felspar crystals are conspicuous, and has a trachytic appearance in hand-specimens. In some specimens dull phenocrysts of a dark colour are visible.

As in so many other Popa rocks these prove to be granular aggregates which probably represent pseudomorphs after hornblende. There are a few crystals of augite sufficiently large to be called phenocrysts, and a few plagioclases, but the bulk of the rock is fine-grained, though holocrystalline, and consists of

[1] Analysis by T. Marrack, A.R.S.M., M.Sc.

granular augite, felspar laths and granules of magnetite. The felspar is much decomposed, with formation of calcite.

### Hill "4,801" Flow.

**Glassy Hypersthene-Augite-Andesite.**—This flow forms one of the highest peaks of the crater rim and dips steeply down towards the south-west.

The rock is usually pale purplish-grey with numerous small white felspars often showing a fluxional arrangement. No dark phenocrysts are visible.

Numerous phenocrysts of felspar, usually water-clear, but between crossed nicols notably zoned, are to be seen. A considerable proportion would seem to be orthoclase, but acid plagioclase is also abundant. There are numerous smaller phenocrysts of augite and many large grains of magnetite. There are a few crystals of the orthorhombic pyroxene described from the rock of the Plantation Flow (see below, p. 423), but in this case they show definite pleochroism and they occur in prismatic or hexagonal sections. The groundmass is hemicrystalline, and consists of turbid, pale-brown glass studded with minute laths of felspar, granules of augite, magnetite and haematite.

**Hornblende-Augite-Andesite.**—This lava is represented by blocks near the Taungbaw Rest House which probably come from a flow in the eastern wall.

The rock is of a handsome pale-grey colour, with numerous dark-brown elongated crystals of hornblende. The specific gravity is 2·48.

The large brown phenocrysts consist of an amphibole with pleochroism from pale greenish-brown to dark red-brown, and with dark borders. The remainder of the rock is fine-grained, with numerous clear plagioclases, small crystals of greenish augite set in a glassy base full of felspar microlites and iron ores. Glass is more abundant in this rock than in most of the Popa rocks.

### The Western Flow.

**Olivine-Basalt.**—By the "western flow" is meant an important lava which now forms the boundary wall of the disrupted crater

on its western side. Perhaps "North-Western Flow" would be a better name, for it probably formed the north-western wall of the crater before its disruption. The flow was examined at its northern end in a deep ravine to the north of the village of Ngayangon.

The rock varies, but is generally dark-grey to almost black in colour, with numerous very large phenocrysts of very dark-green augite. The dark colour of the groundmass renders these phenocrysts less conspicuous than in the rock of the eastern flow.

The large augite phenocrysts, averaging $\frac{1}{4}$ inch across, have the usual characters. They are well formed, have sharp outlines and green tints, with inclusions of magnetite and occasionally of felspar. There are abundant phenocrysts of a basic labradorite, numerous small phenocrysts of olivine with the characteristic cracks outlined by brownish haematite. The remainder of the rock is made up of granular augite, grains of magnetite and lath-shaped felspars together with a few flakes of biotite. Zoning, so characteristic of the andesites, is not observed in these sections. Decomposition is evident in some of the felspars and a moderate proportion of calcite is seen in the groundmass. In some sections yellowish-green serpentine has developed by the alteration of olivine, and it is noteworthy that the groundmass is much coarser than that seen in some of the andesites.

## The Eastern Flow.

**Olivine-Basalt.**—This is a very extensive flow and appears to form the whole of the hill due east of the Taungbaw Rest House, from which point the flow seems originally to have left the crater. From this hill it extends down eastwards and northwards and forms the lava wall on the eastern side of the disrupted portion.

It is a pretty and characteristic rock of pale-grey or pinkish-grey colour, marked by numerous large squarish dark-green phenocrysts of augite. The surface of the flow is darker in colour and vesicular. Blocks of this lava are scattered all round Mount Popa, and the original flow must have been more

extensive than it is now. In appearance the rock closely resembles the Twindaung lava of the Lower Chindwin.

A specimen taken from near the northern end of the flow and about 25 feet below its top is a typical olivine-basalt. Numerous clear olivines accompany a few large crystals of augite and many large plagioclases; these occupy roughly half the bulk of the rock. The remainder is made up of granular augite, magnetite, haematite, a moderate proportion of ragged biotite flakes and felspar laths. The important points are that the dark minerals predominate in the groundmass, the felspars amongst the phenocrysts.

The rock has the following chemical composition:[1]

| | |
|---|---|
| $SiO_2$ | 49·40 |
| $FeO$ / $Fe_2O$ | 10·05 |
| $Al_2O_3$ | 20·35 |
| $CaO$ | 12·10 |
| $MgO$ | 4·78 |
| $Na_2O$ | 2·50 |
| $K_2O$ | 1·06 |
| Total | 100·24 |

### The North-Western Outer Flow.

**Hornblende-Augite-Basalt.**—The end of this flow is well exposed by the side of the main motor road from Welaung to Kyaukpadaung, near milepost 33 m. 5 f.

At the end of a flow, lava, as is well known, breaks up into partially cooled blocks which roll over one another, some becoming squeezed and flattened, others rolling on some distance ahead of the main mass and becoming hardened before being covered up. It is evident that the flows of Mount Popa behaved in the same way and it is the "nose" of such a flow which is exposed by the roadside. As one would expect there is a considerable variation in rock type in a very small area. In general the rocks are dark-grey but often purplish, and contain numerous phenocrysts of greenish augite and dull-brown hornblende.

[1] Analysis by Messrs. D. Waldie & Co., Calcutta.

All the rocks have large, much corroded phenocrysts of dark-brown hornblende (barkevikite), numerous fairly large phenocrysts of augite, and smaller, rather ragged, abundant crystals of plagioclase (mainly labradorite, the larger ones zoned). The groundmass is plentifully spotted with magnetite grains. It consists of a glassy base with felspar laths showing flow structure. In one of the purplish specimens much of the magnetite has changed to haematite or limonite. In some sections the original hornblende has almost entirely disappeared, while in others a considerable proportion remains.

**Iddingsite-Basalt.**—The rock from near Legyi village, Popa road, is light-grey in colour, finely vesicular, and seems to represent the surface of the flow. It is characterised by fewer big phenocrysts of dark-green augite.

A thin section consists of augite, olivine and felspar. The augite is of the usual green colour with inclusions of iron ores, but the phenocrysts are of medium size. The olivine is mostly altered: only in a few sections are "islands" of the unaltered mineral seen. The pseudomorphs are of a reddish-brown colour and show all the characters of iddingsite. In some cases the centre is left unaltered, while in others the exterior border is partially fresh and is of a pale-yellow colour. The felspars are mostly zoned, and rows of inclusions are arranged in a concentric manner, sometimes resembling corona structure. The felspar seems to be acid labradorite or basic andesine. The groundmass is hemicrystalline and consists of a few small laths of felspar, augite and iron ores in a glassy base.

The rock has the following chemical composition :[1]

| | |
|---|---|
| $SiO_2$ | 47·40 |
| FeO | 10·05 |
| $_2O_3$ | 21·80 |
| CaO | 12·25 |
| MgO | 5·68 |
| $Na_2O$ | 1·96 |
| | 1·08 |
| Total - | 100·22 |

[1] Analysis by Messrs. D. Waldie & Co., Calcutta.

### The Plantation Flow.

**Enstatite-Basalt.**—Near the foot of the waterfall, $\frac{3}{4}$ mile north of Hill " 4,502 " and $\frac{3}{4}$ mile south-west of the Taungbaw Rest House, a large number of huge fallen blocks occur in the midst of a banana plantation stretching right to the foot of the crater wall. They consist of enstatite-basalt.

### The Flows of the Western Crater Wall.

A number of flows comprising hornblende-augite-andesites and hornblende-andesites are exposed in the western wall of the crater itself, that is east of Hill " 4,502." Many specimens were collected from fallen blocks and they exhibit a certain community of characters. The rocks from the western wall of the crater are characterised, in the main, by an absence of large or conspicuous phenocrysts. They thus contrast with the eastern flows, where very large and conspicuous phenocrysts of augite are the general rule.

### 10. The Later Ashes, with Bombs.

The later ashes are unconsolidated and of light-grey colours. They often fill up existing valleys, showing that the present drainage system was well developed before the final outbursts of the volcano. In these later ashes bombs from a few inches to two feet in diameter are common, and distinct from broken boulders of lava because of their more or less rounded appearance. They are very abundant on the north-west and north of the crater near the villages of Kanzatkon, Gyaingywa, Ngayangon, etc., and probably were thrown out when the north-western wall of the crater was blown away and the basic andesites and basalts with well developed phenocrysts of augite were erupted.

The rock is invariably very dark, almost black, with dark-green phenocrysts of pyroxene and numerous small steam cavities causing a rough and uneven fracture.

**Vesuvianite-Basalt.**—A bomb of vesuvianite-basalt was collected from Mile 32–2 on the main Popa road. The thin

section consists of a mass of augite and felspar phenocrysts cemented together by brown glass with many vesicles. The rock is characterised by the presence of phenocrysts of vesuvianite, described below and contains:[1]

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ | 51·83 | 0·863 | Quartz | 2·46 |
| $Al_2O_3$ | 17·73 | 0·174 | Orthoclase | 7·23 |
| $Fe_2O_3$ | 3·82 | 0·024 | Albite | 24·10 |
| FeO | 4·16 | 0·057 | Anorthite | 31·97 |
| | | | Diopside— | |
| MgO | 5·70 | 0·142 | $CaO.SiO_2$ | 8·24 |
| CaO | 10·44 | 0·186 | $MgO.SiO_2$ | 6·00 |
| $Na_2O$ | 2·87 | 0·046 | $FeO.SiO_2$ | 1·40 |
| | | | Hypersthene— | |
| $K_2O$ | 1·21 | 0·013 | $MgO.SiO_2$ | 8·16 |
| $H_2O+$ | 0·74 | 0·041 | $FeO.SiO_2$ | 1·85 |
| $H_2O-$ | 0·04 | 0·002 | Magnetite | 5·57 |
| $CO_2$ | — | — | Ilmenite | 1·52 |
| $TiO_2$ | 0·83 | 0·010 | Apatite | 0·34 |
| $P_2O_5$ | 0·21 | 0·001 | | |
| MnO | 0·14 | 0·002 | | 98·84 |
| BaO | 0·08 | 0·001 | Water | 0·78 |
| Total | 99·80 | | Total | 99·62 |

**Vesuvianite-Hypersthene-Olivine-Basalt.**—Another specimen, in addition, contains hypersthene in prismatic sections with inclusions of iron ores and well-marked cleavage traces. The minerals, especially the felspar, occur in rounded grains. Besides these minerals, prismatic sections of vesuvianite, which vary from small stout laths to big elongated plates, are also profusely scattered in the section. They are pale-coloured, with inclusions of iron ores, and are characterised by a high refractive index and pleochroism varying from very light-green to pale-brown. Some clear phenocrysts of olivine are present. Hornblende is conspicuous by its absence.

Specimens of hornblende-pyroxene-andesite are also represented in these bombs. As with the flows it will be noted that both andesites and basalts, sometimes with vesuvianite, constitute the volcanic bombs.

[1] Analysis by T. Marrack, A.R.S.M., M.Sc.

### 11. Ejected Blocks from Mount Popa.

The ejected blocks described below are found as boulders, sometimes in the stream valleys, elsewhere associated with volcanic material. The rocks are all coarse-grained and holocrystalline and are plutonic representatives of the lavas on the surface. Hence they are important in revealing the nature of the roots of the volcano. They appear mostly to be specimens of diorite and gabbro, which in some cases have been afterwards altered to epidiorite. Specimens of hornblende- and epidote-rock also occur as ejected blocks in the area.

### 12. Volcanic Detrital Alluvium.

Volcanic alluvium has partly covered the Peguan on the east, and both the Irrawaddian and the Peguan towards the north and the south. There is not much volcanic alluvium on the west, as few large streams drain the volcanic rocks on that side. Wherever the covering of alluvium has been removed the Tertiary rocks crop out from below, especially in the streams and road cuttings.

The colour of the alluvium is generally greyish-black, though at times brownish, and minerals of the volcanic rocks, especially the ferro-magnesian silicates, can be easily recognised in it. In places small pieces of volcanic rock are often seen associated, as, for example, towards the north.

Patches of similar alluvium, reddish-brown in colour, occur also on the plateau round the main mass of Mount Popa. This red earth, the colour of which may have the same origin as the red earth of the Irrawaddian, probably represents the sub-soil seen on the plateau all round Mount Popa.

### 13. Age.

As Sir Edwin Pascoe has noted, some of these rocks, as, for example, the black tuffs and ashes, are interbedded with the Irrawaddian, proving that activity began in that period and continued subsequently in paroxysmal eruptions. The older andesites constitute the oldest rocks in the area, and have

section consists of a mass of augite and felspar phenocrysts cemented together by brown glass with many vesicles. The rock is characterised by the presence of phenocrysts of vesuvianite, described below and contains:[1]

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ | 51·83 | 0·863 | Quartz - - | 2·46 |
| $Al_2O_3$ | 17·73 | 0·174 | Orthoclase - - | 7·23 |
| $Fe_2O_3$ | 3·82 | 0·024 | Albite - - | 24·10 |
| FeO | 4·16 | 0·057 | Anorthite - - | 31·97 |
| | | | Diopside— | |
| MgO | 5·70 | 0·142 | $CaO.SiO_2$ - - | 8·24 |
| CaO | 10·44 | 0·186 | $MgO.SiO_2$ - | 6·00 |
| $Na_2O$ | 2·87 | 0·046 | $FeO.SiO_2$ - | 1·40 |
| | | | Hypersthene— | |
| $K_2O$ | 1·21 | 0·013 | $MgO.SiO_2$ - | 8·16 |
| $H_2O$ + | 0·74 | 0·041 | $FeO.SiO_2$ - | 1·85 |
| $H_2O$ – | 0·04 | 0·002 | Magnetite - - | 5·57 |
| $CO_2$ | — | — | Ilmenite - - | 1·52 |
| $TiO_2$ | 0·83 | 0·010 | Apatite - - | 0·34 |
| $P_2O_5$ | 0·21 | 0·001 | | |
| MnO | 0·14 | 0·002 | | 98·84 |
| BaO | 0·08 | 0·001 | Water - - | 0·78 |
| Total - | 99·80 | | Total - | 99·62 |

**Vesuvianite-Hypersthene-Olivine-Basalt.**—Another specimen, in addition, contains hypersthene in prismatic sections with inclusions of iron ores and well-marked cleavage traces. The minerals, especially the felspar, occur in rounded grains. Besides these minerals, prismatic sections of vesuvianite, which vary from small stout laths to big elongated plates, are also profusely scattered in the section. They are pale-coloured, with inclusions of iron ores, and are characterised by a high refractive index and pleochroism varying from very light-green to pale-brown. Some clear phenocrysts of olivine are present. Hornblende is conspicuous by its absence.

Specimens of hornblende-pyroxene-andesite are also represented in these bombs. As with the flows it will be noted that both andesites and basalts, sometimes with vesuvianite, constitute the volcanic bombs.

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### 11. Ejected Blocks from Mount Popa.

The ejected blocks described below are found as boulders, sometimes in the stream valleys, elsewhere associated with volcanic material. The rocks are all coarse-grained and holocrystalline and are plutonic representatives of the lavas on the surface. Hence they are important in revealing the nature of the roots of the volcano. They appear mostly to be specimens of diorite and gabbro, which in some cases have been afterwards altered to epidiorite. Specimens of hornblende- and epidote-rock also occur as ejected blocks in the area.

### 12. Volcanic Detrital Alluvium.

Volcanic alluvium has partly covered the Peguan on the east, and both the Irrawaddian and the Peguan towards the north and the south. There is not much volcanic alluvium on the west, as few large streams drain the volcanic rocks on that side. Wherever the covering of alluvium has been removed the Tertiary rocks crop out from below, especially in the streams and road cuttings.

The colour of the alluvium is generally greyish-black, though at times brownish, and minerals of the volcanic rocks, especially the ferro-magnesian silicates, can be easily recognised in it. In places small pieces of volcanic rock are often seen associated, as, for example, towards the north.

Patches of similar alluvium, reddish-brown in colour, occur also on the plateau round the main mass of Mount Popa. This red earth, the colour of which may have the same origin as the red earth of the Irrawaddian, probably represents the sub-soil seen on the plateau all round Mount Popa.

### 13. Age.

As Sir Edwin Pascoe has noted, some of these rocks, as, for example, the black tuffs and ashes, are interbedded with the Irrawaddian, proving that activity began in that period and continued subsequently in paroxysmal eruptions. The older andesites constitute the oldest rocks in the area, and have

undoubtedly flowed over the Peguan rocks. The commencement of the volcanic activity was, therefore, post-Peguan.

As already remarked the main mass of Mount Popa rests on a level plateau, roughly 1,800 feet above the sea-level. This platform represents the surface-level of the land before the building up of the cone, and has been preserved by the resistant capping of lava and tuff. The plateau, therefore, affords a very remarkable gauge of the amount of erosion of the Irrawaddy Series since their final deposition. Though the plateau extends all round Mount Popa it is extremely well-marked on the west. By knowing the rate and amount of erosion in the "Dry Zone" of Burma it is possible to form an approximate idea of the time that has elapsed since the Pliocene period, *i.e.* when Mount Popa was first active. It is noteworthy that no appreciable denudation of the Irrawaddy Series took place before its preservation as a plateau beneath the volcanic rocks, as the volcano appears to have been first active towards the end of the deposition of the Irrawaddy Series. The black tuffs and ashes are either interbedded with the Irrawaddian, with a small thickness of the sands above them, or are only seen at the top of the Irrawaddian.

The village of Popaywa, which stands almost in the centre of the plateau, is marked 1,907 feet above sea-level on the one-inch map, and, therefore, the average height of the plateau may be taken as 1,900 feet. Another point, which is just at the edge of the plateau and from where the steep descent begins, is marked 1,820 feet. The height of the neighbouring plain on which the plateau stands may be taken as 1,034 feet above sea-level, which is the average of four points marked on the map.

Taking 1,820 feet as the height of the plateau constituted by the Irrawaddians and 1,034 the average height of the plain, 786 feet represent the amount of erosion of the Irrawaddians since their final deposition. F. J. Warth [1] has calculated 413 years as required to erode one foot of rock in Mid-Burma from Mandalay to Prome. Multiplying 413 by 786 we get 324,618 years (or about $\frac{1}{3}$ million years in round figures), which gives approximately the time which has elapsed since the Pliocene

[1] Warth, F. J., *Report on the Source, Supply and Agricultural Value of Silt in Burma,* Government Printing Press, Rangoon, 1911.

period and since Popa first erupted. There may be some truth in the legend recorded by Bell[1] that volcanic activity ceased only in historic times. He states: "According to tradition there was a great earthquake in 442 B.C., during which the great cone of Popa rose from the plains, but the native chronicles leave no record of how long it was active and when it became extinct." The author could not find any clue as to the date of the last eruption within the memory of man.

It may be noted in conclusion that the erosion of the plateau must have been practically uniform, since the climatic conditions and gradient of the plateau after the Pliocene period cannot have been very different from those of the present day.

## B. DOLERITES OF THE PEGU YOMA.

Passing farther southwards the intrusive dolerites of the Pegu Yoma are reached. These igneous rocks occur at two widely separated localities. The northern one lies in the Prome district, about 25 miles east of the town of Allanmyo. The only geologist to visit this area previous to the author was the celebrated Theobald, who went there in the 'sixties of the last century; the scale of his map, 1-inch = 8 miles, did not permit him to map these intrusions. He gave the name of "bedded trap" to the igneous intrusive rock. The second area lies in the Tharrawaddy district, about 20 miles east of Zigon railway station on the Rangoon-Prome line.

### 1. Prome Area.

The area described first is situated mainly in the Prome district, though the northern portion lies in Thayetmyo. It lies between latitude 19° 5′ 30″ and 19° 15′ N. and longitude 95° 36′ 30″ E.

The following formations are represented (see Map, Fig. 26):

| | |
|---|---|
| Alluvium - - - - | Recent. |
| Irrawaddy Series - - - | Mio-Pliocene. |
| Post-Peguan Igneous Intrusions. | |
| Pegu Series - - - | Oligo-Miocene. |

[1] Bell, N. C., *The Iron and Steel Work in Burma*, Government Printing Press, Rangoon, 1907.

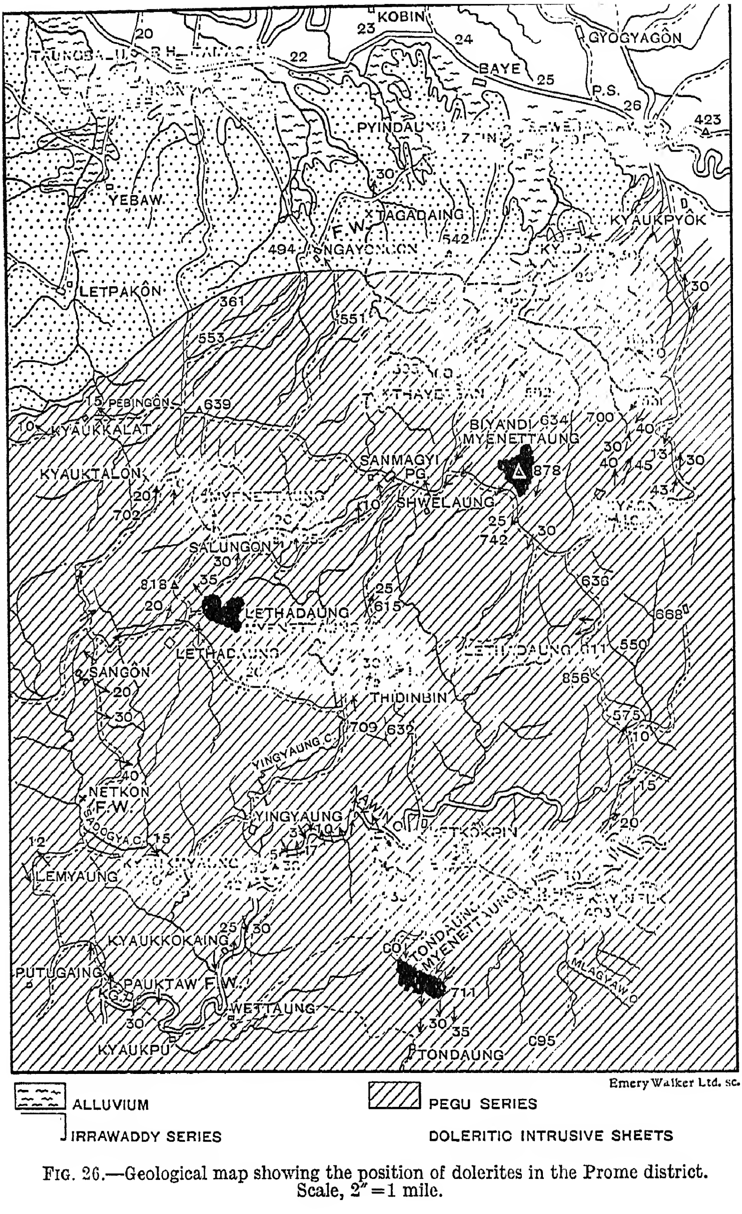


FIG. 26.—Geological map showing the position of dolerites in the Prome district. Scale, 2″ = 1 mile.

A detailed account of the geology of the Pegu and the Irrawaddy Series of this region is given in the author's original paper.[1]

**Igneous Intrusions.**—There are three well-marked igneous intrusions. The rock in each case is a dolerite, and occurs in all stages of alteration. Sometimes the decomposition has proceeded so far that the original characters of the rock have been entirely lost, the final alteration product being a black earth. Because of the existence of the black earth a hill on which it occurs is designated *myenettaung* by the Burmans ("black-earth hill"). The natives, therefore, call the northern locality Biyandi Myenettaung, or East Myenettaung. The conical hill with a precipitous eastern flank is marked "878" on the 1-inch map and forms a conspicuous landmark, as it is the highest

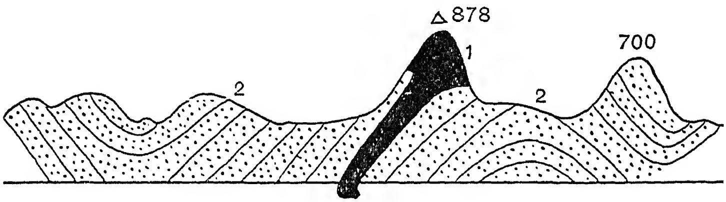


FIG. 27.—Section across "Biyandi Myenettaung" showing the intrusive relation of dolerite. 1=Dolerite, 2=Pegus. Horizontal scale, 1″=1 mile. Vertical scale, 1″=1,000 feet.

point in the area. The lower portion is composed of Pegu clays and interbedded sandstones. The top is built of greyish-black olivine-dolerite (see Fig. 27). The rock is largely altered to black earth, to which Theobald gave the name of "regur." Below this dark-coloured earth lies a white, partially altered material, which is largely calcareous, with pieces of decayed dolerite of yellow or yellowish-brown colours. The fresh dolerite is best seen on the western and south-western flanks.

The southern locality is called "Lethadaung Myenettaung." Theobald seems to have traversed it along the cart track. The east-west extent of the rock is not less than half a mile.

The third occurrence of dolerite is known as Tondaung Myenettaung. In this case its intrusive relationships are best displayed near the spring about three-quarters of a mile north-east of the village of Tondaung. The Peguan rocks dip towards

[1] *Trans. Min. Geol. Inst. Ind.*, vol. xxi, 1927, pp. 338-363.

the south with an average of 30°, and into them the dolerite has forced its way (see Fig. 28). At the contact the clays and sandstones are altered as a result of thermal metamorphism, the former having been converted into shales. The coral limestone, containing an organism comparable to *Hydrophora asteraeoides* from the Miocene of Java, has also been recrystallised as a result of the same agency.

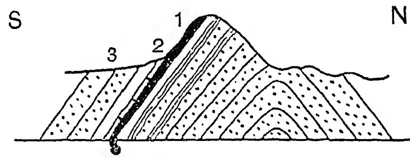


Fig. 28.—Section across Thandaung Myenettaung, illustrating doleritic intrusion along the bedding of the Pegu Series. 1 = dolerite, 2 = limestone with corals, lepidocyclines, 3 = sandstones with siliceous concretions. Horizontal scale, 1″ = 1 mile. Vertical scale, 1″ = 1,000 feet.

A fourth occurrence of black earth and altered igneous rock lies about one mile due north of "Δ 878," or Biyandi Myenettaung, where there is a small outcrop of about one furlong in extent in baked Pegu clays and sandstones. The dolerite, as in the other cases, is largely altered.

**Petrography.**—In hand-specimens the unaltered igneous rock of "878," or Biyandi Myenettaung, has a greyish-black colour and a homogeneous texture, with brown specks of olivine in every stage of decomposition. On weathered surfaces the rock presents a pitted appearance, probably a result of the removal of olivine. The specific gravity is 2·83.

**Olivine-Dolerite.**—Thin sections of the specimens collected from this locality show a plexus of olivine, augite and felspar. "Islands" of unaltered olivine have been left enclosed in yellowish-green serpentine, and in places the alteration is so complete that entire pseudomorphs are seen. Sometimes concentric rings of serpentine with a fibrous structure are developed round olivine or diopside. Parallel growths of olivine are also present. The augite is pale-green in colour, it is quite fresh and exhibits ophitic or sub-ophitic relations with felspar occasionally. Radiating aggregates of augite crystals are also to be observed, suggesting the glomeroporphyritic structure of Professor Judd. Plagioclase felspar (labradorite) forms the groundwork

of the rock, and cross-shaped aggregates of felspar crystals, similar to those of the augite noticed above, are also visible. Magnetite is distributed throughout the rock. In some of the sections zeolites with pinkish to light-brown colour, fibrous radiating structures and low double refraction, have also developed. The rock on analysis [1] showed the following chemical composition:

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ | 48·00 | 0·800 | Quartz | 1·26 |
| $Al_2O_3$ | 18·70 | 0·183 | Orthoclase | 3·89 |
| $Fe_2O_3$ | 3·08 | 0·019 | Albite | 16·77 |
| FeO | 4·29 | 0·060 | Anorthite | 40·03 |
| | | | Diopside— | |
| MgO | 8·30 | 0·207 | $CaO.SiO_2$ | 1·16 |
| CaO | 8·80 | 0·157 | $MgO.SiO_2$ | 0·80 |
| $Na_2O$ | 2·00 | 0·032 | $FeO.SiO_2$ | 0·20 |
| $K_2O$ | 0·72 | 0·007 | Hypersthene— | |
| $H_2O + 105°$ | 3·70 | 0·206 | $MgO.SiO_2$ | 19·90 |
| $H_2O - 105°$ | 1·70 | 0·094 | $FeO.Sio_2$ | 5·02 |
| $CO_2$ | — | — | Magnetite | 4·41 |
| $TiO_2$ | 0·30 | 0·004 | Ilmenite | 0·61 |
| $P_2O_5$ | 0·10 | 0·001 | Apatite | 0·34 |
| MnO | 0·20 | 0·003 | | |
| S | — | — | | 94·39 |
| | | | Water | 5·40 |
| Total | 99·89 | | Total | 99·79 |

**Alteration.**—The serpentinisation of olivine and diopside has already been mentioned. Sometimes calcite pseudomorphs replace augite. In some rocks spherules of brownish palagonite occur, including isotropic as well as anisotropic types. In places it shows an orange colour and is anisotropic; here the mineral, as presumed by Dr. Fermor,[2] may be chlorophaeite. On account of the change the groundmass assumes a darker aspect and it appears as if there might be some glass in the rock, but under high powers the groundmass proves to be holocrystalline.

Several nodules of crystalline calcite were picked up from hill "878," but it is difficult to say whether they originated from magmatic or meteoric waters; the writer inclines to the

[1] Analysis by W. H. Herdsman.

[2] *Rec. Geol. Surv. Ind.*, vol. lviii, 1925, p. 133.

former view, considering the changes that the rock has undergone.

A rock from Tondaung Myenettaung, of a greyish-green colour, shows white veinlets of chalcedony. It is highly altered and consists of irregular blebs of palagonite of varying sizes, the largest being about 1 inch in diameter. It effervesces with dilute hydrochloric acid, and with concentrated acid it immediately assumes a bright-green colour.

A thin section under the microscope shows orange-coloured palagonite, which appears to have resulted from the alteration of all the minerals in the dolerite. Pseudomorphs of chlorophaeite after laths of felspar are interesting. The mineral is anisotropic and shows closed fibrous radiating structures. Dark isotropic palagonite is also present. Silica, in the form of chalcedony, seems to have either filtered into the rock or to have separated during the processes of alteration. A remarkable point about this section is the colour change observed on heating. The uncovered thin section showed a clear yellowish-brown, but on covering and heating it assumed a greenish-black colour. Apparently the change may be attributed to the dehydration of palagonite.

## 2. Tharrawaddy Area.

The second area lies in the Tharrawaddy district, about 17 miles north-east of Zigon railway station, on the Rangoon-Prome railway line. The only earlier reference to this area was made by Mr. Watson,[1] and until the writer's visit in March 1926 it had apparently been examined by no other geologist. Mr. Watson wrote as follows : "There is an outcrop of intrusive rock in compartment 39, Bawbin, a specimen from which was identified by the Superintendent, Geological Survey of India, as an augite-porphyrite." The area is difficult of access.

**Igneous Intrusions.**—The biggest igneous intrusion (see Fig. 29) is situated in the centre of the Forest Block 39 and is locally known as Kyaukyi Taung (meaning "big stone hill"). The Ngayan *chaung* runs in numerous serpentinous curves round its

[1] Watson, H. W. A., "A Note on the Pegu Yoma Forests," Government Printing Press, Rangoon, 1923.

northern crescent. There is a small hill of the same rock on the north of the big hill across the Ngayan *chaung*. The igneous rock is undoubtedly intrusive, as the contact shales belonging to the Pegu Series are highly baked, indurated, bleached and contorted. In places the shales have been changed into hornfels. Xenoliths of altered shale and sandstone are enclosed in the

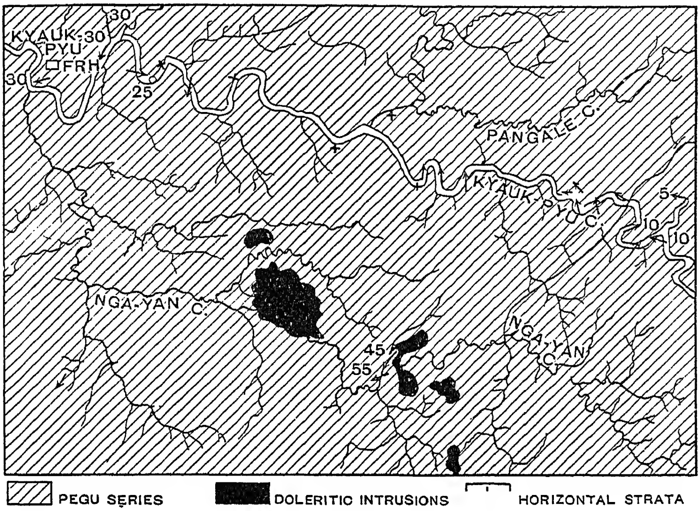


FIG. 29.—Geological map showing the position of some of the doleritic intrusions in the Tharrawaddy district.

boulders of dolerite. Specimens showing " lit-par-lit " injection of dolerite in the country rock were picked up from the southern hill, east of " Three Falls," in the Ngayan *chaung*.

Another interesting intrusion is situated east of the main hill and is best exposed in the Ngayan *chaung* (Plate XIX, Fig. 2). This occurrence is locally known by a name meaning " Three Water Falls." The first fall is composed of baked shales, dipping south-west at high angles of 55° (see Fig. 30). The igneous rock dips sharply into the shales as a result of the jointing at right angles to the bedding. Then, at a distance of about 100 feet downstream, there is another waterfall in igneous rock dipping at rather high angles with the sedimentary rock. At a short distance below the third fall occurs. It is again determined

by rather steep beds of hard, baked shales dipping south-west. The dolerite appears to be a small sill which continues both northwards and southwards and has cut through the shales. The latter show contact effects such as induration, bleaching and incipient development of contact minerals and spots (observed under the microscope).

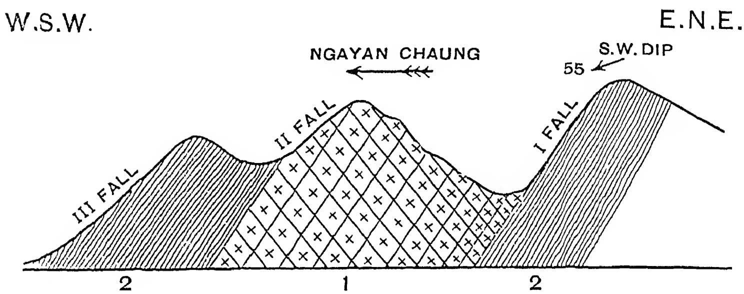


FIG. 30.—Section showing the " Three Falls Intrusive Sill " in the Pegu Series in the Ngayan chaung, Kyaukpyu, east of Zigon, Tharrawaddy district. 1 = Dolerite showing jointing. 2 = Pegu shales.

Similar intrusions of dolerite continue southwards, as is clear from the accompanying map. In places it appears that the igneous intrusion has not been laid bare, for overlying sandstones and shales appear greatly altered and broken, with a few pieces of exposed dolerite at the surface. Further outcrops of igneous rock may be expected towards the south.

**Olivine-Dolerite.**—The rock from the lower slopes of the eastern flank of Kyaukyi Taung is light-grey in colour, with a coarse texture in which felspar, augite and olivine can be recognised with a pocket lens. The weathered surface presents a pitted appearance, probably owing to the removal of olivine. The specific gravity of the rock is 2·80.

A thin section consists of a plexus of felspar laths, with phenocrysts of augite and olivine. The augite appears to be malacolite and is non-pleochroic; it shows lamellar twinning. Several irregular patches of yellowish-green serpentine are also visible. It is typically fibrous in places; the mesh-structure is mostly wanting and kernels of unaltered diopside and olivine rest inside the serpentine. Inclusions of iron ores are present. Laths of plagioclase felspar form the groundmass of the rock;

it is largely altered, in some places to saussurite, in others to calcite. A little biotite is also present.

The rock on chemical analysis [1] yielded the following results :

| | | Molecular Proportions. | | Norm |
|---|---|---|---|---|
| $SiO_2$ | 49·70 | 0·828 | Orthoclase | 7·78 |
| $Al_2O_3$ | 18·04 | 0·176 | Albite | 26·20 |
| $Fe_2O_3$ | 2·10 | 0·013 | Anorthite | 27·52 |
| FeO | 4·92 | 0·068 | Nepheline | 3·69 |
| MgO | 7·65 | 0·191 | Diopside— | |
| CaO | 9·50 | 0·170 | CaO.$SiO_2$ | 7·54 |
| $Na_2O$ | 3·90 | 0·063 | MgO.$SiO_2$ | 5·10 |
| $K_2O$ | 1·35 | 0·014 | FeO.$SiO_2$ | 1·85 |
| | | | Olivine— | |
| $H_2O + 105°$ | 1·80 | 0·100 | 2MgO.$SiO_2$ | 9·80 |
| $H_2O - 105°$ | 0·10 | 0·006 | 2FeO.$SiO_2$ | 4·08 |
| $CO_2$ | Nil. | — | Magnetite | 3·02 |
| $TiO_2$ | 0·45 | 0·005 | Ilmenite | 0·76 |
| $P_2O_5$ | 0·29 | 0·002 | Apatite | 0·67 |
| MnO | 0·20 | 0·003 | | |
| S | Nil. | — | | 98·01 |
| | | | Water | 1·90 |
| Total | 100·00 | | | |
| | | | Total | 99·91 |

**Alteration.**—Complete serpentinisation of the ferro-magnesian minerals has usually taken place, but sometimes pseudomorphs of calcite replace these minerals. Fibres of pale green serpentine penetrate the felspars also. Irregular patches of serpentine are occasionally found within the large felspar crystals. Sometimes a few sections of breunnerite occur, some of which present rhombic outlines. Pseudomorphs with idiomorphic outlines characteristic of olivine seems to have first altered to serpentine and then into carbonates, while the interior is filled with felspar. In some rocks talc is present in large irregular patches. Within the irregularly oriented, stellate clusters of talc, which appears pinkish in ordinary light, a few unaltered crystals of augite remain. The formation of serpentine and talc points to a hydrothermal replacement.

Sometimes the felspar seems to have been entirely replaced by a fibrous zeolite with straight extinction. It possesses a very low refractive index, a very low interference colour and is

[1] Analysis by W. H. Herdsman.

probably thomsonite. All these changes, therefore, viz., serpentinisation, carbonatisation, zeolitisation, silicification, etc., provide definite evidence of the rock having undergone hydrothermal change. The volatile constituents involved in bringing about these changes were largely heated $H_2O$, $CO_2$ and $SiO_2$. These vapours and gases were probably emitted by the magma during its final stages of consolidation.

Besides chlorophaeite, pseudomorphs of reddish-brown palagonite without any fibrous structure are present. It appears that this palagonite has developed by the alteration of all the ferro-magnesian minerals present in the rock. Unaltered augite and biotite are definitely seen to pass into palagonite through the intermediate stages of decomposition. Dr. Fermor [1] has already noted the development of palagonite from primary glass, augite and felspar, but in this case chlorophaeite has been produced from biotite as well. In some sections delessite, a few sections of secondary quartz and lussatite were also observed.

**Contact effects.**—The contact effects of these doleritic intrusions are not particularly well marked except as regards the bleaching, baking, and induration of the shales.

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3. Chhibber, H. L., "Rhythmic Banding of Ferric Oxide in Silicified Rhyolite Tuffs," *Geol. Mag.*, vol. lxiv, 1927, pp. 7-9.

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[1] *Rec. Geol. Surv. Ind.*, vol. lviii, 1925, p. 133.

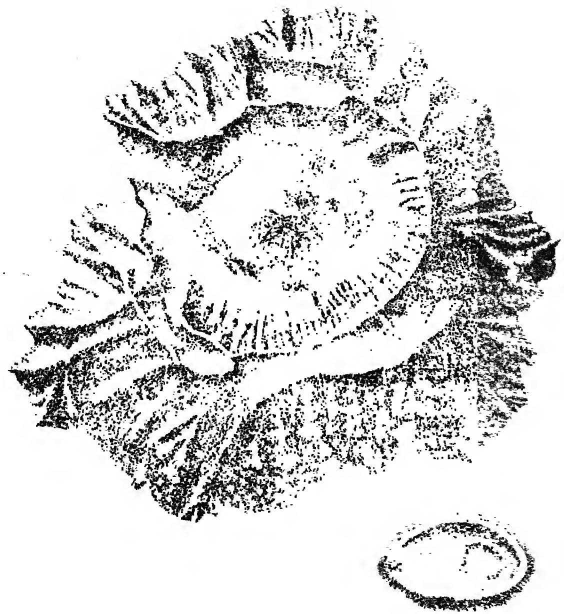


FIG. 1.—MAP OF BARREN ISLAND, BAY OF BENGAL. PLAN OF INNER CONE IS SHOWN BELOW.

FIG. 2.—MAP OF NARCONDAM ISLAND, BAY OF BENGAL.

# CHAPTER XXXI

## IGNEOUS ACTIVITY (*Contd.*)

## VARIATION IN TIME

## A. VOLCANOES OF NARCONDAM AND BARREN ISLAND

FARTHER south, though outside Burma, yet on the same line, are situated the volcanic islands of Narcondam and Barren Island (see Plates XXI and XXII), which deserve special mention for several reasons. Firstly, their rocks bear a very close similarity to those of Burma, and in reality the volcanoes themselves form a southern continuation of those of Burma. Secondly, they are the only volcanic islands in the Bay of Bengal; while Barren Island, perhaps, constitutes the only instance of an active volcano in these seas. Both of them rise abruptly out of comparatively deep water, and may, therefore, perhaps furnish material for the modern petrologist who desires to study the nature of magmas which have not been affected by surface contamination and assimilation. It is regrettable that, being situated in rather out of the way places, they have not yet received the full treatment they deserve.

### 1. Narcondam.

**Topography.**—Narcondam lies about 75 miles N.N.E. of Barren Island. Like the latter it rises abruptly out of deep water, depths of about 450, 565 and 562 fathoms being noted on the chart within about one kilometre from the island in various directions. Its area is 2·78 square miles, and it has an oval outline. Its greatest length, north-east—south-west, is about 2·5 miles, and its greatest width about 1·75 miles. It has a roughly conical form, with sides deeply scored by ravines. The

summit, 2,330 feet above the sea, is rather to the south of the centre of the island and it bears no crater. The culminating portion of the volcano includes three hummocks, of which the northern is the highest. The shore is cut away by wave action into steep cliffs, up to several hundreds of feet high.

The lavas that build Narcondam, according to H. S. Washington, are very uniform in composition. Mallet described them as hornblende-andesite, but Washington in accordance with modern terminology, designated them dacite, as his analyses showed that the silica content is much too high for andesite, although little or no quartz is visible.

**Hornblende-Andesites.**—The specimens of lava collected from the highest point of the mountain and from different localities on the slopes and around the coast are all compact or very slightly vesicular rocks, in which crystals of white translucent felspar and black or dark-brown hornblende, with occasional biotite crystals, are disseminated through a groundmass, which is generally light-grey in unweathered specimens. According to H. S. Washington the felspar phenocrysts comprise orthoclase, andesine and calcic-plagioclase, about labradorite $Ab_1$ $An_2$. The first two minerals are mainly untwinned and show central clusters of minute inclusions. The crystals of dark yellowish-brown hornblende are about as large as those of the felspar, but are far less numerous. An occasional dark-brown biotite is seen, and large sections of hornblende and biotite show very dark margins. Magnetite and apatite also occur. The groundmass is microcrystalline and mainly felspathic, being composed of andesine with specks of augite, hornblende, magnetite and biotite. Some grains of quartz are also present with some glass, but the former mineral is not prominent.

H. S. Washington analysed two specimens of dacite from Narcondam Island, with the following results. The molecular proportions and norm of the analyses are also given on opposite page.

The analyses are similar and bear resemblance to dacitic rocks from other localities, and do not call for any special comment.

**Agglomerates.**—Volcanic agglomerates composed of rounded and angular fragments of lava of every size up to three or four

feet in diameter, embedded in a finer matrix, are exposed in sections along several parts of the coast.

As stated by Washington, Mallet believed, because of the "acid" and very uniform character of the rocks and the absence of a crater and of ash, that the island is a domal eruption.

| | I | II | Molecular Proportions. I | Molecular Proportions. II | Norms. | I | II |
|---|---|---|---|---|---|---|---|
| $SiO_2$ - | 61·31 | 61·24 | 1·022 | 1·020 | Quartz - - | 18·06 | 17·58 |
| $Al_2O_3$ - | 16·80 | 16·86 | 0·165 | 0·166 | Orthoclase - | 11·12 | 12·23 |
| $Fe_2O_3$ - | 3·73 | 3·97 | 0·023 | 0·024 | Albite - - | 27·25 | 27·25 |
| FeO - | 1·60 | 1·41 | 0·022 | 0·019 | Anorthite - | 25·85 | 25·58 |
| MgO - | 3·06 | 3·07 | 0·076 | 0·076 | Diopside - | 5·62 | 4·97 |
| CaO - | 6·86 | 6·62 | 0·122 | 0·118 | Hypersthene | 5·10 | 5·40 |
| $Na_2O$ - | 3·21 | 3·23 | 0·052 | 0·052 | Magnetite - | 0·46 | — |
| $K_2O$ - | 1·84 | 2·11 | 0·019 | 0·022 | Ilmenite - | 3·19 | 3·04 |
| $H_2O+$ - | 0·26 | 0·11 | 0·014 | 0·006 | Haematite - | 3·36 | 3·97 |
| $H_2O-$ - | 0·06 | 0·09 | — | 0·006 | Apatite - - | 0·34 | 0·34 |
| $TiO_2$ - | 1·66 | 1·60 | 0·020 | 0·020 | | | |
| $P_2O_5$ - | 0·14 | 0·13 | 0·001 | 0·001 | | | |
| MnO - | 0·09 | 0·09 | 0·001 | 0·001 | | | |
| Total | 100·62 | 100·53 | | | Total - | 100·35 | 100·36 |

I. Hornblende-dacite, Summit, Narcondam Island—Analyst, H. S. Washington.

II. Hornblende-dacite, North side, 1,400 feet above sea-level, Narcondam Island—Analyst, H. S. Washington.

## 2. Barren Island.

Barren Island lies approximately in 12° 15′ N. Lat. and 93° 50′ E. Long., and is about 100 kilometres east of the southern end of Middle Andaman Island. According to Oldham, "Soundings show that the cone rises from a depth of 800 fathoms below the sea." Barren Island is of an almost circular form with an area of 3·07 square miles. Most writers on vulcanology have regarded these islands as situated in the continuation of that great zone of volcanic energy which stretches for some 2,000 miles along the Sunda group of islands, the terrible activity of which was illustrated by the explosive eruption of Krakatoa in 1883.

The island consists of an almost circular ridge with heights varying from about 600 feet above sea-level on the north-west to 1,160 feet on the south-east. On the western side there is a deep breach, giving entrance to the interior of the oval crater. It has a diameter of about a mile and its floor has altitudes above sea-level of about 80 feet near the landing-place to 319 feet east of the central cone. Towards the south-east the slopes, rising to a height of 700 or 900 feet above the floor of the crater, or some 1,100 above the sea, are well wooded. On the north they are much less steep and high, with rounded outlines towards the top, and are largely covered with loose, black, naked ash.

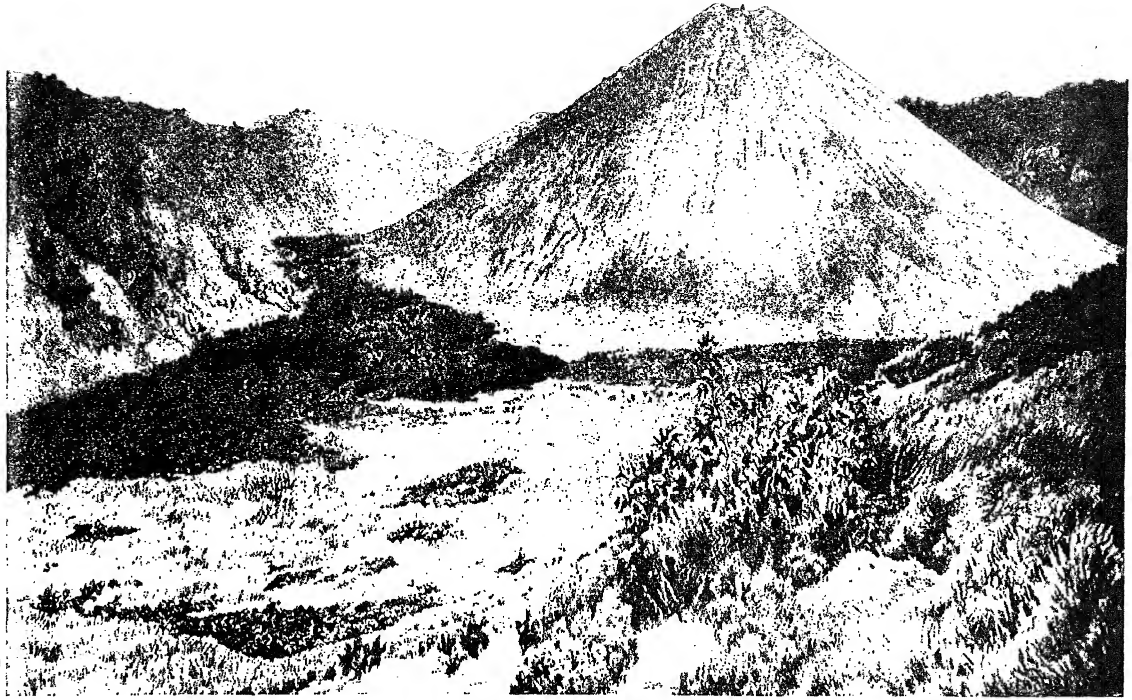
**Central Cone.**—In the centre of the crater the central cone rises to a height of about 1,015 feet above the sea, or about 700 to 900 feet from its western foot with, as seen from the west, an almost perfectly symmetrical outline, the sides preserving an even slope of 22° (see Plate XXII). The truncation at the summit marks the site of the crater, and here a thin column of steam rises slowly into the air.

**The Recent Crater.**—The recent crater is of an ovoid form with the major axis lying about S. by W.–N. by E. The highest points of the edge, to the north and south, are 78 feet above the floor. The materials inside the crater are loose blocks of lava, scoriae and ash, but to the south-west of the bottom there is a mass of solid lava, which is probably in connection with a flow down the side of the cone which has been covered over by the latest eruption of fragmentary material. The floor has a diameter of 60 feet.

**Streams of Lava.**—Almost encircling the base of the cone are streams of lava, one of which has poured through the breach into the sea. They are all covered with rugged black and scoriaceous crusts, and with fissured and hummocky surfaces.

The crater rim is higher on the south-east. Mallet ascribed the fact that the north-western half of the volcano is of lower elevation than the other half to a bodily sinking of that side.

But it may equally well have been lowered by one of the explosive outbursts, during which the north-western side was partially blown away. Similarly, the northern side of Mount Popa is of lower elevation than the other sides, and also has a



CENTRAL CONE AND CALDERA OF BARREN ISLAND, FROM THE WEST.

breach in that lower wall, and probably the same explanation applies. Moreover, the evidence of the Akyab coast and of the Andaman and Nicobar Islands points to a recent uplift of land and not to a subsidence.

**Lavas of the Ancient Cone.**—The ancient cone of Barren Island is largely made up of lava. The specimens described by Mallet are more or less vesicular, with small crystals of white translucent felspar and small granules and crystals of bottle-green, translucent augite, disseminated through a dark-grey groundmass. Brownish-yellow olivine is frequently present also. The felspar is triclinic and contains glass enclosures and numerous black opaque particles, many of which have the shape of magnetite crystals. The groundmass is microcrystalline, and is made up of minute crystals of plagioclase felspar, with augite and nearly or quite opaque specks which appear to consist of more or less decomposed augite with some magnetite. In some specimens the porphyritic felspar crystals are thickly strewn; in others they are comparatively few, and the same is true of augite. Frequently olivine is also present, and in rare cases it replaces the augite almost completely. An average sample of the lavas yielded 49·55 per cent. of silica. Three compact specimens were found to have specific gravities of 2·77, 2·80 and 2·87. Most of the specimens submitted to examination may be designated doleritic basalt, while some verge towards anamesite according to Mallet.

**Fragmentary Ejectamenta of the Ancient Cone.**—Fragmentary ejectamenta interstratified with the lavas of the ancient cone are exposed in some few good sections along the coast. In some places the scoriae are rudely interbedded with irregular layers of lava. One hundred yards north-west of the landing-place a somewhat contorted bed of black volcanic ash is interstratified with a similar alternation of scoriae and lava. They show miniature faults of a few inches throw by which the bed has been dislocated.

**Recent Ash on Ancient Cone.**—A considerable part of the ancient cone, including both the walls of the crater and the exterior slopes, are covered with ash ejected from the central cone. The greater proportion occurring to the north and north-east may be ascribed partly to the influence of the south-west

monsoon, partly to the crater rim being lower there. The newer ash differs from most of the older in being nearly or quite black instead of dull red.

**Flows of the Central Cone.**—According to Mallet there are three distinct flows of quite recent lava, which may be distinguished as the eastern, the southern and the northern streams. In general appearance they are all very similar to one another, presenting the same exceedingly rough, hummocky and fissured surfaces with the black scoriaceous crust broken into pieces of every size up to those many tons in weight. The lava streams have the lateral and terminal banks so frequently noticed in the case of Mount Popa and other volcanoes.

The recent lavas, like those of the ancient cone, consist of white, translucent, triclinic felspar crystals, and bottle-green translucent augite, with frequently a little olivine in a microcrystalline groundmass composed of triclinic felspar, augite, magnetite, opacite, apatite, etc. This description compares perfectly with the recent olivine-basalts of the Twindaung type from the Lower Chindwin and Mount Popa areas.

**Southern Flow.**—The southern stream broke out a little more than half-way up the cone, at a point now marked by a slight projection. After pouring down the side of the cone it followed the course of the valley into the sea, which has since then cut the face into a cliff 10 or 15 feet in height. This was the largest flow of all, a considerable part of the area covered by it being obscured by the sand which has been washed down from the old crater walls to the south. There seems to have been a subsequent minor gush from the orifice which scarcely reached beyond the base of the cone.

**Northern Flow.**—The northern stream broke through at about 250 feet below the crater; close to the point of issue there is a solfatara with an opening 8 or 9 inches in diameter. From the mouth steam issued copiously. From the point of issue the molten rock, after reaching the base of the cone, flowed down the valley and over the previous stream from the south, the termination of the later flow being marked by a bank a little to the west of the cone. Mallet believed that the lava had been emitted within a quite recent period, almost certainly within the last century.

**Recent Aqueous Deposits.**—In the lower part of the main gorge, which debouches to the south of the alluvial plain, there is an agglomerate composed of rounded and angular lumps of volcanic rock in a finer matrix which appears to be a deposit of the stream itself. At the mouth of the gorge to the north of the anchorage another aqueous deposit may be seen, and doubtless there are many others on the island.

**Hot Springs.**—There are springs of hot water, with a temperature of 116° F. in 1884, which gush forth on the beach at the landing-place. The shore between the cliffs of ancient lava and the recent stream has a length of about 40 yards, and along it the hot water issues in numerous places from the shingle. The level of the springs rises and falls with the tide, and when first observed in 1832 the rocks were so hot that the "stones on shore, and the rocks exposed on the ebbing of the tide, were smoking and hissing and the water was bubbling all around them."

Mallet ascribed the high temperature of the water to the recent lava and the scoriaceous and other porous material beneath it not having yet completely cooled. The temperature of the spring is gradually falling, as is to be expected, due to the gradual cooling of the lava.

**Physical and Geological History of the Volcano.**—The physical and geological history of the volcano can be divided as follows :

(1) The first and the important phase must have formed the volcano which is now represented by the outer amphitheatre. It is made up of scoriae, ash, agglomerates, and basaltic lava.

(2) The second stage consisted of a great paroxysmal eruption, when part of the crater was blown off and the present breach was formed. Probably the sea invaded the inner part of the volcano at the same time.

(3) The third stage built up the central pile, which consists of newer fragmentary ejectamenta, ash, scoriae, agglomerate, and lava flows.

(4) Lastly, the flows of recent lava welled out, some of which Mallet believed were not even a century old.

(5) Since the welling out of lava streams the volcano has been seen in activity by several observers, ejecting red-hot stones, flames, smoke, steam, and sulphur vapour. The last are responsible for the deposits of sulphur seen in the solfataras.

Washington has described the petrology of some of the rocks of Barren Island, including a basaltic tuff and specimens of augite-andesite and olivine-free basalt.

**Augite-Andesite.**—The specimens of augite-andesite described by him came from 100 yards north-east of the landing-place and also from a bay half a mile south-west of the landing-place. The rock is decidedly porphyritic with phenocrysts of felspar up to 2 mm. in size and very rarely a slightly larger augite, in a dense aphanitic, slightly pinkish-grey groundmass. Under the microscope a thin section shows the composition of the plagioclase felspars to vary from about $Ab_1\ An_1$ to $Ab_1\ An_2$, many of them with a very thin outer border of more sodic material. Some of the sections show simple Carlsbad twinning or none at all. Pyroxene phenocrysts are few, but there are some small olivines, most of which are well shaped. The abundant groundmass is equigranular, and is composed of small grains of felspar, apparently mostly andesine, with grains of colourless or slightly brownish augite, and some magnetite; hornblende and biotite are absent.

Two chemical analyses of rocks of this type are given in the following table, with their molecular proportions and norms. According to H. S. Washington No. I. is possibly from one of the recent flows, and No. II. from a flow in the ancient "Somma." They greatly resemble each other. The norms show a little excess silica, so that the olivine phenocrysts must be regarded as non-essential, merely unabsorbed relics of an early stage of crystallisation.

**Basalt.**—The specimen described by Washington from the coast near the north point of the island consists of an olivine-free labradorite-basalt. It is a vesicular rock with a medium grey colour. Some phenocrysts of labradorite and fewer of black augite are scattered through the aphanitic grey groundmass. In thin section it shows larger and more abundant phenocrysts of a labradorite more calcic than that seen in the andesite described above, with many colourless phenocrysts of augite in a somewhat indefinite groundmass similar to that of the andesite described above. There is little olivine, no quartz, but glass is perhaps present, though it is difficult to be certain. The chemical analysis of the specimen No. IV. in the table differs

| | I. | II. | III. | IV. | Molecular Proportions. I. | II. | III. | IV. | | Norms. I. | II. | III. | IV. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 52·97 | 53·72 | 53·57 | 49·07 | 0·883 | 0·895 | 0·892 | 0·817 | Quartz | 9·84 | 7·08 | 4·08 | 0·96 |
| $Al_2O_3$ | 19·18 | 18·14 | 16·22 | 17·24 | 0·188 | 0·177 | 0·159 | 0·169 | Orthoclase | 2·78 | 5·56 | 3·89 | 3·89 |
| $Fe_2O_3$ | 3·15 | 2·66 | 1·80 | 4·77 | 0·019 | 0·016 | 0·011 | 0·029 | Albite | 24·63 | 28·82 | 34·06 | 18·34 |
| $FeO$ | 4·20 | 4·95 | 7·54 | 4·71 | 0·058 | 0·068 | 0·104 | 0·065 | Anorthite | 37·81 | 31·14 | 24·19 | 35·31 |
| $MgO$ | 2·88 | 3·31 | 3·89 | 8·34 | 0·072 | 0·082 | 0·097 | 0·208 | Diopside | 10·63 | 13·13 | 13·70 | 16·26 |
| $CaO$ | 10·68 | 9·79 | 8·61 | 11·46 | 0·190 | 0·175 | 0·154 | 0·205 | Hypersthene | 4·12 | 4·52 | 11·15 | 14·92 |
| $Na_2O$ | 2·88 | 3·41 | 3·97 | 2·16 | 0·046 | 0·055 | 0·064 | 0·034 | Magnetite | 4·64 | 3·94 | 2·55 | 6·96 |
| $K_2O$ | 0·50 | 0·91 | 0·64 | 0·65 | 0·005 | 0·010 | 0·006 | 0·017 | Ilmenite | 3·65 | 5·17 | 5·17 | 3·65 |
| $H_2O+$ | 1·00 | 0·44 | 0·93 | 0·07 | 0·056 | 0·024 | 0·052 | 0·004 | Haematite | — | — | — | — |
| $H_2O-$ | 0·03 | 0·08 | 0·04 | 0·08 | 0·002 | 0·004 | 0·002 | 0·005 | Apatite | 0·67 | 0·34 | 0·67 | 0·34 |
| $TiO_2$ | 1·94 | 2·74 | 2·70 | 1·85 | 0·024 | 0·034 | 0·034 | 0·023 | | | | | |
| $P_2O_5$ | 0·27 | 0·19 | 0·22 | 0·08 | 0·002 | 0·001 | 0·002 | 0·001 | | 98·77 | 99·70 | 99·46 | 100·63 |
| $MnO$ | 0·11 | 0·08 | 0·12 | 0·09 | 0·001 | 0·001 | 0·001 | 0·001 | Water | 1·03 | 0·52 | 0·97 | 0·15 |
| Total | 99·79 | 100·42 | 100·25 | 100·57 | | | | | Total | 99·80 | 100·22 | 100·43 | 100·78 |

I. Augite-andesite, west-north-west of central cone, south of point 632, Barren Island—Analyst, H. S. Washington.
II. Augite-andesite, 100 yards north-east of landing-place, Barren Island—Analyst, H. S. Washington.
III. Augite-andesite, bay, one half mile south-west of landing-place, Barren Island—Analyst, H. S. Washington.
IV. Basalt, coast, near north point of island, Barren Island—Analyst, H. S. Washington.

markedly from the first three, and is that of a basalt rather rich in lime. It is noteworthy that the amount of $TiO_2$ is less in the basalt than in the andesites.

Washington has pointed out that the descriptions, chemical analyses and the norms suggest a very close relationship between the rocks of Narcondam and Barren Island. As described above, the rocks of Barren Island comprise augite-andesite with some basalt, in which neither hornblende, biotite, nor any notable amount of quartz appear. The lavas of Narcondam, so far examined by Dr. Washington, seem to be uniformally hornblende-dacite, with augite in the groundmass, some biotite, and with some visible and more conjectural quartz.

The norms of the rocks show that these differences are largely modal, and due in large part to the conditions of extrusion. All the lavas show excess of silica (normative quartz). The potash is constantly low but still not negligible. The felspars become regularly more calcic as the rocks are less salic and quaric ; and the diopside and hypersthene of the norm, in all of which magnesia dominates over ferrous oxide, become more and more magnesic as the rocks become more salic and quaric. According to Washington these chemical and normative relations point conclusively to derivation from a common magma, a conclusion substantially supported by the geographical position of these two islands. The lavas of Barren Island were extruded as flows, with much ash, etc., while those of Narcondam, according to Mallet, formed a domal eruption. This difference in the mode of eruption was brought about by differences in the chemical composition of the two local magmas.

The relationships of the rocks of these two islands with those of the other parts of Burma are discussed in the sequel.

## B. IGNEOUS OCCURRENCES ALONG THE EDGE OF THE SHAN PLATEAU.

Passing eastwards we come on to the igneous occurrences connected with the important boundary fault marking the edge of the Shan Plateau. On this line are situated the teschenites, olivine-dolerites and olivine-basalts (mugearites) of the Kabwet area, and rhyolites and rhyolite tuffs of the Thaton district.

### The Igneous Rocks of the Kabwet Area, Shwebo and Mandalay Districts.

The area lies between 22° 33′ and 22° 49′ of north latitude and 95° 54′ and 96° 0′ of east longitude, and falls within the Districts of Shwebo (west of the river Irrawaddy) and Mandalay (east of the river).

About latitude 22° 44′ the Irrawaddy makes a sudden and remarkable right-angled bend to the west and flows westwards for about two miles before resuming, somewhat more gradually, its normal southerly course. The remarkable change in general direction in this region is determined by the presence of the lava plateau of Singu to the south (see Geological Map, Fig. 31), around the northern and western edge of which the river now swings. There can be little doubt that the lava was poured out across the valley of the river and the river itself, and that the present course is comparatively recent.

About half-way through the east-and-west stretch of the river is the village of Kabwet, on the northern bank. A conspicuous feature to the north-west of Kabwet is the Hill 734, or Nattaung, marking the position of the main doleritic intrusion.

From Kabwet southwards the river gradually broadens out, but as far south as Singu, where the lava plateau ends, there is a considerable contrast between the lava plateau on the east and the Tertiary sands on the west. The main lava plateau really ends some few miles north of Singu, but there are outliers, separated by alluvium, at least as far south as the town itself. The lava plateau of Singu is a remarkable feature. It presents an almost level surface, being upwards of 150 feet above river

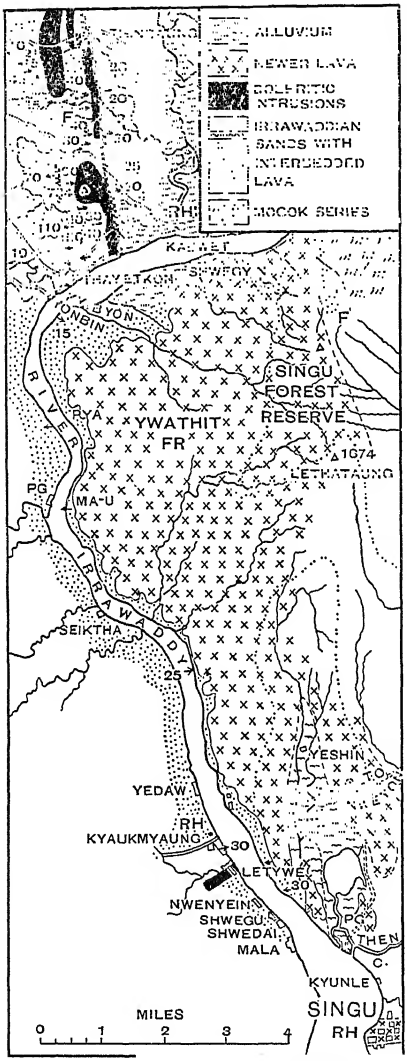



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FIG. 31.—Geological sketch-map of the Kabwet area, Shwebo and Mandalay districts, Upper Burma.

level. The surface of the lava slopes very gently upwards towards the east, until one commences the sudden rise to Lethataung (1674 feet).

The general geology of this region is comparatively simple. The rock groups present are as follows :

| | |
|---|---|
| **Recent** - - | Alluvium. |
| | The Younger Lava of Singu. |
| **Tertiary** - - | "Irrawaddian" sands with the Older Lava (interbedded) and the doleritic intrusions. |
| **Archean** - - | Mogok Gneisses and Crystalline Limestones. |

## 1. The Older Lava.

One of the most interesting and remarkable rocks in the Kabwet area is the lava which occurs interbedded with the Irrawaddian rocks and has already been described above. (p. 355).

## 2. The Intrusive Rocks.

The intrusions of dolerite and teschenite are, as stated above, younger than the Older Lava. They have, however, been exposed by denudation and extensively weathered, and are thus probably considerably older than the Younger Lavas.

The largest intrusion is that forming Nattaung (Hill 734). It appears to be laccolitic in form, being intruded into the eastern limb of the anticline. The present mass presents a long dip slope to the east and a steep scarp slope to the west. Practically the whole of the scarp slope, that is, the western slope of Hill 734, consists of the dolerite, which must there reach a considerable thickness. To the north and south it soon becomes thinner and seems to die out when the river section is reached. The rapid thinning prevents one regarding the intrusion as a sill.

The anticlinal axis passing through the Nattaung hill is followed by a synclinal axis running through Kabwet, and similar doleritic dykes are observed on the other side of the synclinal limb.

Similar doleritic dykes are also met with in other localities, one near the village of Kyaukmyaung, and another exposed on the banks of the river at Singu. The former is intrusive into the sandstones, which are mostly yellow in colour and become pebbly towards the south. The direction of the dyke appears to be N.E.–S.W., and not E.–W. as recorded by T. Oldham.

On the banks of the river at Singu there is a small exposure of lava, the upper portion being highly vesicular, open and porous and having the same megascopic and microscopic characters as the rest of the lava towards the north. This is underlain by more compact rock which shows spheroidal weathering, peeling off in successive coats, so that the weathered surface presents more or less circular nodules varying in size from a walnut to about a foot or even more in diameter.

The occurrences of intrusive rocks may be described under three headings:

(*a*) The main laccolitic mass of Nattaung, sheet 734.
(*b*) The smaller intrusions of Letkokpin and neighbourhood.
(*c*) The dykes of Kyaukmyaung and Singu.

## (a) Nattaung (Hill 734)

**Megascopic Characters.**—The rock of the Nattaung hill is compact, greenish-black in colour and with medium texture. With a pocket lens laths of felspar, light-green olivine and black pyroxenic crystals can be recognised. This rock is much more crystalline than the lava on the opposite bank of the river. The specific gravity is 2·81.

**Microscopic Characters.**—This rock shows a tendency towards porphyritic structure, and contains moderately large crystals of olivine and felspar. The latter mineral occurs in hypidiomorphic plates and has a columnar habit. Some of the crystals of felspar are traversed by transverse cracks. The felspar shows zoning in some cases and inclusions of minute prisms of apatite are quite common. Sometimes the felspar is untwinned (sanidine ?) but simple and lamellar twinning are normally to be seen. The olivine is quite colourless and occurs in rounded or hypidiomorphic plates with acute terminations in places. It is often wholly or partially enclosed by augite, giving rise to poikilitic structure. Serpentinisation has set in and the olivine has either wholly or partially changed to serpentine. Where the change is partial, "islands" of unaltered olivine remain. In one of the slides the olivine has changed to yellowish or greenish-yellow serpentine instead of bluish as noted before. In some sections the mineral has changed to serpentine with the

liberation of haematite, and is thus stained red. Magnetite occurs in all the minerals. The titan-augite is pale purple in colour and is pleochroic. It rarely builds idiomorphic crystals, but occurs either in small hypidiomorphic plates or in irregular or rounded crystals (granular structure of Judd). Minute grains of augite often occur in circular clusters with small laths of the same mineral diverging from it, suggesting kelyphitic structure.

The interstitial material consists of narrow lath-shaped crystals of felspar, sometimes crossing one another, with small grains of augite and magnetite. Besides this, in places pale-brown isotropic glass is seen filling the remaining spaces. It is remarkable that this pale-brown glass passes insensibly sometimes into a colourless mineral with low refraction and mainly isotropic, but sometimes showing very low polarisation colours such as greys of the first order. This mineral appears to be primary analcite. It is noteworthy that it was the last mineral to crystallise, and hence the analcite and glass are often seen in juxtaposition filling interspaces. It is very likely that the composition of the glass is not very different from that of analcite, and by a molecular mixture of the composition of the glass and the analcite, a different mineral with anomalous double refraction has been produced. The rock is thus an olivine-dolerite with analcite and deserves the name of teschenite.

In the table on next page is tabulated the chemical analysis[1] of the rock from 734 Hill, with the molecular proportions and norm.

**Olivine-Dolerite.**—A thin section of a specimen from the road to the south of Nattaung shows subophitic structure extremely well developed while the olivine is much more altered than in the teschenite. Isolated crystals of augite display optical continuity, and there is a tendency towards micrographic intergrowth of augite and felspar. It is remarkable that in this section there is little or no pale-brown residual glass and analcite, and the rock seems to be an ordinary olivine-dolerite. It is, therefore, concluded that whilst the main hill of Nattaung (734) is composed of a typical teschenite the margins of the intrusion are of simple olivine-dolerite, suggesting local differentiation of the mass.

[1] Analysis by T. Marrack, A.R.S.M., M.Sc.

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $SiO_2$ | 49·22 | 0·820 | Orthoclase | 8·90 |
| $Al_2O_3$ | 17·35 | 0·170 | Albite | 32·49 |
| $Fe_2O_3$ | 2·25 | 0·014 | Anorthite | 23·07 |
| FeO | 6·35 | 0·088 | Nepheline | 2·56 |
| | | | Diopside— | |
| MgO | 6·07 | 0·151 | $CaO.SiO_2$ | 4·99 |
| CaO | 7·71 | 0·138 | $MgO.SiO_2$ | 3·10 |
| $Na_2O$ | 4·47 | 0·071 | $FeO.SiO_2$ | 1·58 |
| | | | Olivine— | |
| $K_2O$ | 1·51 | 0·016 | $2\ MgO.SiO_2$ | 8·40 |
| $H_2O+$ | 2·55 | 0·141 | $2\ FeO.SiO_2$ | 4·69 |
| $H_2O-$ | 0·25 | 0·014 | Magnetite | 3·25 |
| $CO_2$ | Nil. | — | Ilmenite | 2·74 |
| $TiO_2$ | 1·46 | 0·018 | Apatite | 1·34 |
| $P_2O_5$ | 0·62 | 0·004 | | |
| MnO | 0·19 | 0·003 | | 97·11 |
| BaO | 0·03 | — | Water | 2·80 |
| Total | 100·03 | | Total | 99·91 |

An altered specimen reveals a much greater preponderance of iron ores than in the fresh sections. A considerable amount of secondary haematite has been produced by the thorough alteration of olivine, no trace of which is left now. The augite does not seem to have altered much, and only a slightly deeper pinkish-purple tinge has developed. This mineral is also distributed in the section in very fine needles and often in radiating groups. The felspar is absolutely fresh and is only stained yellowish or reddish-brown with haematite. It occurs in radiating or sheaf-like subvariolitic aggregates.

### (b) Kyaukmyaung and Singu.

Two other occurrences of dolerite are those of Letywe (about half a mile to the south of Kyaukmyaung, Shwebo District, and Singu, Mandalay District).

*Olivine-Dolerite.*—The rock, collected from near the river, about half a mile to the south of Kyaukmyaung is massive, medium-textured, thoroughly basic in appearance and of a greenish-black colour.

*Microscopic Characters.*—Thin sections shows a plexus of plagioclase laths and ophitically related augite with serpentine

pseudomorphous after olivine. The laths of felspar build cross-shaped aggregates, and the mineral is partly saussuritised in places. The titan-augite is purplish in colour and is pleochroic. The original olivine is wholly altered to serpentine, which shows various shades of deep, light and yellow-green and light-brown colours. A few pseudomorphs of haematite, occasionally with those of altered augite, are derived from this mineral. Mesh structure is typically absent from the serpentine.

In addition to these minerals there is a light-brown glassy base filling in the interspaces in places, but it is not absolutely isotropic, indicating that devitrification has set in.

**Analcite-Dolerite.**—An intrusive rock from a quarter-mile south of Letywe village is interesting, as zeolites form a very large part of it. The felspars do not form the whole framework of the rock, but the laths of this mineral are scattered about in colourless patches of zeolites. Olivine is wholly altered. It is an exception to find that the augite is almost colourless or has a much lighter colour than that seen in the other slides. The coloured sections of titan-augite are pleochroic, from pale pink to pinkish-purple, and have an extinction angle of 43°.

Besides these minerals there are colourless patches of zeolites which are either isotropic or show grey polarisation colours. In places these patches occur in radiating aggregates and exhibit undulatory extinction. It appears that these patches consist partly of analcite and partly of other zeolites. This was confirmed by microchemical staining after gelatinization with hydrochloric acid, when it was observed that all the minerals described as zeolites were beautifully stained, leaving augite and felspar uncoloured. Magnetite occurs as an accessory mineral. It is noteworthy that these dolerites of Letywe have a larger proportion of zeolites than any other rock examined in the area.

### 3. Mugearite-Basalt.

The Younger Lava, or Mugearite-Basalt, is confined to the south of the River Irrawaddy, and extends from opposite the village of Kabwet as far as the town of Singu, and occupies an area of at least 24 square miles. It forms a roughly horizontal

sheet resting on the denuded edges of the folded Irrawaddian rocks (see Fig. 32).

The first thing which strikes one about the younger lava is its remarkably fresh, unaltered appearance. Apart from the fact that the plateau is covered with a forest of tall trees one might be standing on a flow of lava scarcely yet cool. In places the surface has the well-known "ropy" appearance, in other places it is very vesicular, elsewhere compact.

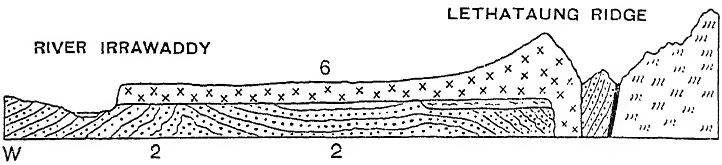


FIG. 32.—Section through the Singu lava plateau.

It is believed that the eruptions of lava occurred through fissures and one of them passed through the highest point of Lethataung (1,674 feet), from which the lava slopes.

**Megascopic Characters.**—The lava has a light to dark-grey colour and is highly vesicular. In places it becomes scoriaceous and often amygdaloidal, but compact specimens are not wanting. It is remarkable that, side by side with highly vesicular lava, quite compact and hard masses are also to be seen. This holds good at the edge of the lava plateau, as well as near the top, but it may be mentioned that the mass becomes a little more compact towards the centre. Many specimens exactly resemble the lavas of existing volcanoes in showing "ropy" and tachylytic surfaces, etc. Sometimes minerals, such as olivine, pyroxene and felspar can be detected with a lens. Though T. Oldham recorded the composition of the rock as consisting of equal proportions of hornblende and felspar, actually the former mineral is absent from the rock. The weathered specimens in places assume a greyish-red colour owing to the liberation of iron from the ferro-magnesian minerals. The average specific gravity of the rock is 2·68.

**Microscopic Characters.**—Under the microscope a specimen one mile north of Pya, from the edge of the plateau, is seen to contain phenocrysts of colourless olivine, felspar and augite. The olivine is relatively fresh, with little signs of serpentin-

isation. It occurs mostly in idiomorphic sections with squarish or rectangular outlines. Only in places along the cracks, or on the margins, is there a yellowish tinge due to iron staining. Inclusions of iron ores and felspars are seen in the mineral. Felspar occurs mainly in elongated laths in which small inclusions of olivine, augite and ilmenite are present. It is twinned both on the Carlsbad and albite laws, and some of the sections show zonary banding. The plagioclase felspar is oligoclase-andesine.

The hemicrystalline groundmass consists of minute laths of felspar, granules of olivine, pale-purplish augite and magnetite. In places needles of augite are aggregated together. They are pleochroic, the colour changing from pinkish to purple. Extinction in certain cases is straight, with low polarisation colours, while other examples exhibit an extinction angle of 39°, with bright polarisation colours of the second and third orders. It appears, therefore, that both orthorhombic and monoclinic pyroxenes are present. The rock appears to be very rich in soda, as observed from the nature of the felspars and augite, and therefore is a species of **Mugearite,** though it differs from the typical rocks of this type in several respects : the presence of augite among the phenocrysts, etc.

A rock from the edge of the lava plateau, near Inkadi, is greyish-black and vesicular, and under the microscope shows phenocrysts of labradorite with augite and olivine set in a greyish-black groundmass. The outlines of the felspar crystals are not sharp, but show corroded margins. The augite is greyish-purple in colour and is often seen in radiating needles or in arborescent aggregates. Olivine is stained orange-red with haematite. Magnetite is very profusely present in the sections and is arranged in peculiar dense aggregates, in rod-like, dendritic or arborescent forms. It is possible that part of this greyish-black material represents the residual glass in the section.

**Olivine-Tachylyte.**—In hand specimens the rock from the slope of the Singu Reserved Forest Ridge on the way to Nweyon is of an iron-black colour with a resinous lustre. It is vesicular in texture, the cavities being lined with green substances, probably ferro-salts.

Under the microscope a thin section contains phenocrysts of colourless olivine and clear laths of felspar, which are set in a

brown glassy base. In addition, the section contains incipient growths of brownish crystallites and microlites of augite, skeletal crystals of felspar, etc. In places the brown laths have assumed shapes similar to those of normal crystals, but they have not completed their crystallisation so as to be acted upon by polarised light. The felspar has preceded the crystallisation of augite. It is noteworthy that glass forms the largest proportion of this rock.

Another specimen of a similar olivine-tachylyte from about one mile east of Shwegyin village is markedly scoriaceous. The specimen is greyish in colour with white phenocrysts. Under the microscope phenocrysts of felspar, olivine and augite are set in a brownish glass. It is noteworthy that the crystals of felspar form the great proportion of the phenocrysts in the rock. In places they possess quite angular and irregular outlines, showing that the crystals were broken during eruption.

The highly cellular, pumiceous and scoriaceous nature of this rock proves that the lava was poured out under very slight pressure, and that it probably represents the original uppermost surface.

The following is an analysis[1] of a typical mugearite from this area with its molecular proportions and norms :

| | | Molecular Proportions. | | Norm. |
|---|---|---|---|---|
| $S_1O_2$ | 51·69 | 0·860 | Orthoclase - | - 18·35 |
| $Al_2O_3$ | 17·17 | 0·168 | Albite - | - 32·49 |
| $Fe_2O_3$ | 2·09 | 0·013 | Anorthite - | - 20·02 |
| FeO | 6·15 | 0·085 | Nepheline - | - 0·28 |
| MgO | 5·53 | 0·138 | Diopside— | |
| CaO | 6·62 | 0·118 | CaO.$SiO_2$ | - 3·94 |
| | 3·91 | 0·063 | MgO.$SiO_2$ | - 2·60 |
| $K_2O$ - | 3·15 | 0·033 | FeO.$SiO_2$ | - 1·06 |
| | | | Olivine— | |
| $H_2O$ + - | 1·07 | 0·059 | 2MgO.$SiO_2$ | - 7·84 |
| $H_2O$ − - | 0·13 | 0·008 | 2FeO.$SiO_2$ | - 4·08 |
| $TiO_2$ - | 2·13 | 0·027 | Magnetite - | - 3·02 |
| $P_2O_5$ - | 0·63 | 0·004 | Ilmenite - | - 4·10 |
| MnO - | 0·11 | 0·003 | Apatite - | - 1·34 |
| | | | | 99·12 |
| | | | Water - | - 1·40 |
| Total | - 100·43 | | Total | - 100·52 |

[1] Analysis by T. Marrack, A.R.S.M., M.Sc.

### 4. Metamorphic Phenomena connected with the Younger Lavas.

The contact effects of the basaltic flows are slight, and only one case deserves special notice. Near the junction of the lava and Tertiary rocks on the road to Nweyon, numerous light-grey, compact, fine-textured nodules were found. It was thought in the field that they were lava bombs, but microscopic examination proved them to consist apparently of altered calcareous shale.

In thin section a large quantity of calcite is seen scattered through the slides in minute granules. When this calcite is removed with the help of hydrochloric acid the characters of the remainder of the rock are more easily studied. The whole is very fine-grained : the most conspicuous feature is the presence of clear, broken crystals, often with concave outlines, and probably of quartz. There are numerous very minute laths which appear to be of felspar. Other similar flakes show bright polarisation colours and are possibly of mica. These crystals and crystallites are set in an isotropic glassy base. It is suggested that the rock is a fused shale (buchite) in which the alteration has not been sufficiently intense to give rise to well-formed crystals of any metamorphic minerals, though they may be present as crystallites. The abundance of calcite is noteworthy, and is probably secondary, *i.e.* deposited by circulating waters.

### 7. Origin of the Teschenites and Mugearites.

The rocks of this region are alkaline in type : the intrusions are teschenites or analcite-dolerites, and have the typical purplish augite so well seen in the similar rocks of the Midland Valley of Scotland, whilst the extruded lavas are also of sodic types, with sodic plagioclase in many cases and purplish augite in all cases. The rocks thus offer a remarkable contrast to the igneous rocks of the same age lying in the central belt of Burma described above, only some 30 or 40 miles to the west of Kabwet, and which possess calc-alkaline affinities.

The minerals, soda-orthoclase, oligoclase-andesine, titaniferous augite, analcite, etc., are unique in this area. Furthermore,

the presence of soda-orthoclase in the groundmass strongly confirms the alkaline affinities of the magma. The mineralogical evidence is further substantiated by chemical testimony, as the analyses of the teschenites and mugearites contain the highest percentage of alkalies known at the present day in similar rocks in the whole of Burma. Furthermore, it is noteworthy that both in the teschenites and mugearites, soda predominates over potash.

The author has little doubt that the teschenites, analcite-dolerites and mugearites, known to occur in this region alone in the whole of Burma, have been formed by the syntexis of limestone and basalt. Here at both surface and depth there occurs Mogok gneiss, with which are associated bands of crystalline limestones, calc-gneisses and calc-granulites. There is very little doubt that these rocks furnished the amount of lime required to produce the alkaline rocks in question. Farther north, as already shown on pp. 123-124, nepheline-bearing rocks, containing also the complementary diopside, have been formed at the contact of a vein (six to eight feet thick) of felspar rock, mostly albite, and intrusive into the Archaean marble. It must be borne in mind, however, that R. A. Daly stresses the importance of water, assimilated by basaltic magma from wall- and roof-rocks, in the genesis of these analcite-bearing types.[1] An occurrence of basic alkali rocks containing nepheline and melilite attributable to assimilation of chalk by basaltic magma has been described by Dr. C. E. Tilley from Scawt Hill, Co. Antrim, Ireland. The author suggests that the case under description furnishes another instance of the restricted potentiality of igneous magma to generate alkali types by assimilation of limestone. It may be noted that this particular case constitutes one of syntexis mainly at depth before the intrusion or extrusion of the magma.

The trend of igneous activity can be explained as follows: first the magma as a result of Pleistocene orogenic movements rose and assimilated limestone and intruded itself into the folds of the Irrawaddians as teschenites, olivine-dolerites, etc. Farther south, perhaps a little later, more violent movements occurred, and the same syntectic magma poured forth itself on the surface of the Irrawaddians as mugearites and allied basalts.

[1] "Igneous Rocks and the Depths of the Earth," 1933, pp. 474-5.

## C. KYAUKSE DISTRICT.

Farther south, during the year 1912, P. N. Datta surveyed the eastern parts of the Irrawaddy lying in the districts of Kyaukse and Meiktila and bounded on the east by the hills of the Shan States. According to him felsite and andesite occur in this region, but their relationship to the other rocks is not known.

## D. THE THATON DISTRICT, LOWER BURMA.

Southwards on this line of the main boundary fault along the edge of the Shan plateau and the Tenasserim Yoma occur the rhyolites and rhyolite tuffs of the Thaton district, Lower Burma.

The area is situated in the township of Sittang, Thaton district, and is about seven and a half miles to the east of the Mokpalin railway station situated on the Rangoon-Moulmein railway line. The locality lies in the north-east corner of the one-inch map sheet No. 94/G3 and 7 (old No. 353). The band of lava runs for at least six miles in a north-south direction and continues on to the north into unsurveyed territory. One of the southernmost hills on the band of volcanic rocks is marked ·500 on the above-mentioned map sheet. The band of volcanic rocks lies between lat. 17° 25′ and 17° 30′ north and long. 97° 2′ east.

### 1. General Geology.

In the area the following formations occur in descending order:

(1) Alluvium.
(2) Laterite and similar earth.
(3) Rhyolites and rhyolite tuffs.
(4) Granites.
(5) Sedimentary series consisting of shales and sandstones partially metamorphosed. Probably of Carboniferous age.
(6) Gneisses.

It should be noted that the granites and the gneisses of this area are not all of the same age as grouped by Theobald in his Martaban group. The gneisses are older than the sedimentary series, while the granites appear to be younger and may be intrusive into the shales and sandstones of this area.

The volcanic rocks have flowed over the shales and argillaceous sandstones. The sedimentary rocks possess all shades of black, yellowish and reddish colours. In places they are highly metamorphosed and have almost changed into hornfels or argillites, indicating the superheated character of the rhyolitic lava. They are very hard, especially in the neighbourhood of the lava. The shales are highly contorted, flexured, and locally show high dips, becoming almost vertical, *e.g.* west of Kyauktaga gorge in Khawa *chaung*. Sometimes the sedimentary rocks seem to dip towards the volcanic rocks. The strike of the sedimentary series is north-north-west—south-south-east.

Near the contact the shales are generally visible for a short distance (probably due to denudation), but generally these are hidden below the alluvium or lateritic earth.

In the south there are two hills east of Inkabo (east) village, and from the north-western hill a narrow band of rhyolites and rhyolite tuffs extends northwards for several miles, when it passes beyond the northern extremity of the one-inch sheet No. 94/G3 and 7 into the unsurveyed region. On account of the hard capping of volcanic rocks a low ridge, slightly broken in places, forms the foothill of the Tenasserim Yoma. The width of the volcanic band is very small, seldom exceeding half a mile, and in places dwindles down to about 100 feet. The Khawa *chaung* has cut a beautiful gorge in these lavas near Kyauktaga village.

The tuffs seem to predominate, but flows of true rhyolite are not absent, though the latter are small and thin. The composition of the tuffs is not different from that of the rhyolites, only they are clastic in origin.

## 2. Rhyolites.

The rhyolites show various shades of light-pink, light-grey to almost greyish-black colour, and are generally very hard and

sometimes break with a splintery fracture. They usually exhibit flow structure which becomes very pronounced when the light-grey and slightly pink bands alternate. Sometimes the rock is vesicular and in the vesicles silica is seen. These under the microscope resolve themselves into roughly hexagonal tablets of tridymite. The weathered surface has a reddish appearance, but the rock is on the whole quite fresh.

A specimen from about half a mile north-west of Kyauktaga village is light-grey in colour, showing well-marked banded and fluxion structures.

A thin section under the microscope shows a coarse-textured mosaic of quartz and orthoclase felspar, with a similar microcrystalline mosaic forming the matrix which is holocrystalline. A few tiny microlites of muscovite are present. Sometimes this mineral occurs as irregular flakes in the rock, when it deserves the name of muscovite-rhyolite. A few specks of magnetite are also to be seen. Some crystals show staining due to limonite.

The rock from three-quarters of a mile north-east of Kyauktaga village is greyish-black in colour and shows an excellent fluxion and banded structure on account of which a pseudo-slate-like appearance is seen. The rock is very hard but is traversed by cracks along which it breaks with a splintery fracture. The specific gravity is 2·61. Under the microscope a thin section consists of a microcrystalline mosaic of quartz and microlites of felspar. The rock is rather singular in showing irregular and imperfect crystals of magnetite forming arborescent and branching aggregates in places.

### 3. Rhyolite Tuffs.

The rhyolite tuffs show pinkish, yellowish, greyish to greyish-black colours and are composed of fragments of rhyolite with a siliceous matrix. Sometimes the fragmental rocks include flow-breccias, etc.

A specimen taken from near the Kyauktaga gorge in the Khawa *chaung*, near Kyauktaga village, is hard, tough, greyish in colour with white veins of silica especially near the margin. It is slightly vesicular and the vesicles are lined or completely filled with minute crystals of tridymite.

A thin section consists of fragments of rhyolite, some of which show a fibrous appearance, probably due to fluxion arrangement. Some pieces are composed of a very fine mosaic of quartz and microlites of felspar with a little glass, while in others broken crystals of quartz and felspar are clearly embedded. Along the lines of flow are arranged blackish and brownish particles of probably magnetite and haematite respectively.

**Rhyolite-Flow-Breccia.**—Specimens taken from about two miles north-east of Inkabo Kwin (east) consists of a rhyolite-flow-breccia in which dark fragments of rhyolite are welded together with a similar matrix, and the flow structure is conspicuous. Fragments of baked shale are enclosed in the lava. The specific gravity is 2·59. A thin section consists of a very fine microcrystalline mosaic of quartz and felspar with some coarse-grained patches also. The remarkable point about the section is that it shows many streaks or irregular patches of colourless mica (sericite) which appear to have developed as a result of contact metamorphism, or it may be due to the assimilation of sedimentary material. Irregular patches of a yellowish, somewhat fibrous mineral are also distributed in the section, and may represent palagonite or viridite which is only partially acted upon by polarised light. Bright red haematite is widely distributed in the section.

**Tuffaceous Rhyolite.**—The rock from one mile east of Kyauktaga village shows a grey colour with a network of veins of whitish chalcedony. In the vesicles and other interstices perfect crystals of quartz which are sometimes coated with iron ores have developed. The specific gravity is 2·54.

A thin section under the microscope is very interesting in showing pale-yellow bands of chalcedony running in all directions. It appears that thermal waters containing silica and iron salts percolated along the interspaces and round the vesicles between the different fragments. So rings of chalcedony are seen round the fragments of rhyolite which consist of cryptocrystalline mosaics of quartz and felspar. Colourless aggregates of crystalline quartz have been deposited in the vesicles.

### 4. Comparison of the Rhyolites of Thaton with those of Pavagad, Kathiawar, Malani, Bawdwin, Kyaukpadaung (Mount Popa) and the Lower Chindwin.

It may be advantageous to compare similar rocks described from India and Burma. These include rhyolitic lavas from Pavagad (Kathiawar), Malani (Rajputana) and Bawdwin (Burma), Kyaukpadaung and the Lower Chindwin. Dr. Fermor has described the rocks of the Pavagad hill, and shows that they are more basic in character and differ in the following respects from the Malani rocks.

(*a*) " Quartz phenocrysts are much more frequently absent in the lavas of Pavagad than in those of Malani." It should be noted here that the lavas under description are almost wholly devoid of phenocrysts. The bigger crystals seen sometimes filling the vesicles are of secondary origin.

(*b*) " The felspar phenocrysts are often plagioclastic, frequently as basic as andesine in the Pavagad rocks while they are almost orthoclastic in Malanis." The present author found no trace of plagioclase felspar in the rocks described above and the felspar present is untwinned orthoclase.

(*c*) " Augite phenocrysts are of fairly frequent occurrence in the Pavagad rhyolites and completely absent except for one doubtful exception noticed by Mr. La Touche in the Malanis." No phenocryst of any other ferro-magnesian mineral except muscovite could be detected in the Thaton lavas.

Acid volcanic rocks of almost the same age as those of Malani occur in Burma in the Bawdwin volcanic stage, which is no doubt older than Ordovician, and offers many points of contrast to the lavas in question. The Bawdwin rhyolites exhibit flow, spherulitic and perlitic textures, corrosion of quartz phenocrysts, etc. The groundmass is always cryptocrystalline, having probably undergone a certain amount of devitrification. The Bawdwin rhyolites resemble those of Malani in having a preponderance of quartz phenocrysts over those of felspar, and in the absence of plagioclase felspar and of augite. La Touche further remarks that the felspars of the Bawdwin rhyolites are usually decomposed both in the phenocrysts and in the groundmass, and are represented by a fibrous felted mass (?)

sericite which also fills cracks in the groundmass; sometimes the outlines of the crystal are still preserved, and in some cases traces of simple twinning are still visible. No trace of ferro-magnesian minerals or of mica was observed in the Bawdwin rhyolites. But the author's slides did not reveal any spherulitic and perlitic textures; nor were these textures observed in the similar rocks from Mount Popa and the Lower Chindwin. In none of these late Tertiary rhyolites described from Burma were any well-marked quartz and felspar phenocrysts observed. With regard to the decomposition of the felspar of the Bawdwin rhyolites the present rocks are quite unaltered.

Hence it would appear that the Thaton lavas present a marked contrast to those of the Pavagad lavas and are undoubtedly more acidic in character. They differ also from the Malani and Bawdwin rhyolites, as shown above. But it is very remarkable that the Thaton rhyolites appear to form a suite with the Kyaukpadaung (Mount Popa region), the Lower Chindwin and the Jade mines, Myitkyina district, rocks which they seem to resemble in every respect.

## THE LATE-TERTIARY IGNEOUS OCCURRENCES OF YUNNAN AND THE SHAN PLATEAU.

Finally, the igneous occurrences connected with the warping of the Shan Plateau and the hill ranges to the south will be considered. They comprise the volcano of Loi Han Hun in the Northern Shan States and the basalt of Medaw Island in the Mergui district. Though the volcanic rocks in the neighbourhood of Têng-Yüeh in south-west Yunnan are situated outside Burma yet they lie on the same tectonic belt, and for the sake of comparison and completion are included here.

### A. The Teng-Yueh Volcanoes, South-west Yunnan.

John Anderson was the first observer to give a general description of the volcano She-toe-Shan. L. Von Loczy, who later traversed the Têng-Yüeh district, has given a brief account of this volcano. He was the first to recognise the difference in

age between the older " ash grey, biotite-amphibole-andesites " of the Pagoda Hill near Têng-Yüeh and felspathic basaltic lavas poured forth from She-toe-Shan itself. Dr. Coggin Brown visited the area about the year 1912 and discovered the other extinct volcanoes of Lao-Kuei-po, Tay-in-Shan and the cones of the Kung-po group in addition to those already known.

### 1. She-toe-Shan.

The area occupied by She-toe-Shan and its associated lava fields is an elongated oval approximately six miles in length from north to south and four miles wide at its broadest part. The lavas abut on to the vicinity of the market town of Mien-Chien, and on the east they flow over the older bedded platy andesites around Têng-Yüeh and the granites of the Pao-fung-tzu range.

Although She-toe-Shan has been quiescent within historic times nothing is more evident than its recent appearance. Erosion and denudation have made little impression upon it. The lower part of the volcano and all the flows around are made up of one type of rock, a black, slaggy, pumice-like material consisting of scoriaceous lava. The height of She-toe-Shan above the level of the plain on which it stands is estimated to be about 900 feet. The steep crater wall does not extend completely round, but is blown out somewhat towards the north.

### 2. Lao-Kuei-po.

The extinct volcano, Lao-Kuei-po, lies about two miles to the west of Têng-Yüeh and rises to a height of 800 feet above the northern side of the small Ho-Shuen-Shan plain. The slopes of the cone are very regular, with no rock outcrops visible from a distance on its sides.

The crater wall is almost circular save where it is blown out on the west side overlooking the Mien-Chien plain. The crater itself is about 100 feet deep and 200 yards across. The lower slopes are clothed with fine forest, and higher up thick grass hides all good exposures of rock. The small outcrops which

were found all consisted of a very light pumice-like rock, so full of steam-holes that small pieces float on water. From the greater denudation it has suffered it is evident that Lao-Kuei-po is older than She-toe-Shan.

### 3. Tay-in-Shan.

The volcanic origin of this hill, which forms such a prominent feature of the landscape to the north of Têng-Yüeh, was first suspected by Loczy; its general outline and long sloping sides are clearly visible even from a great distance away.

It lies eight miles to the north-north-west of Têng-Yüeh and rises to a height of 9,400 feet above the sea and some 3,250 feet above the general elevation of the Têng-Yüeh plain. It is entirely composed of black, slaggy, pumice-like lavas which continue from base to summit. In appearance they are practically identical with the lavas of She-toe-Shan. At the base the slaggy black lavas are seen in contact with the underlying granite. The crater wall is missing on the south-east side, thus giving to She-toe-Shan the double-topped appearance it possesses when viewed from the south.

### 4. The Kung-po Volcanoes.

Dr. Coggin Brown gave this name to a group of small craters of the " Puy " type from the name of the sub-division of the Têng-Yüeh district in which they are situated. Looking south from the high ground to the north of Ku-tung-kai no fewer than seven small craters can be seen, including Tay-in-Shan.

In addition to the above some more volcanoes have been suspected. The mountain Yao-wu-shan (7,200 feet) to the north of Ku-tung-kai has all the appearance of an old volcano; similarly the high peak Lutsung-shan (8,800), visible from Têng-Yüeh, may be of similar origin. George Forest, who accompanied the late Consul, G. S. Litton, informed Dr. Coggin Brown that hills of crateriform aspect were met with on their journey, and it is probable that extended examination will reveal further volcanic foci in this direction.

PLATE XXIII.

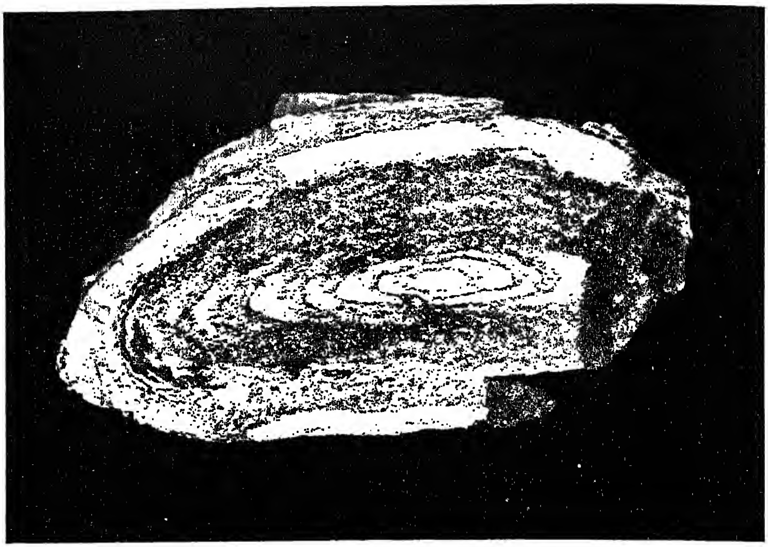

Fig. 1.—A "PILLOW" OF OLDER LAVA, KABWET AREA, SHWEBO DISTRICT, SHOWING CONCENTRIC STRUCTURE.

Fig. 2.—SUMMIT OF LOI HAN HUN, NORTHERN SHAN STATES.

### 5. Older Andesites.

In addition to the above lavas there are greyish-blue, and occasionally reddish-grey, close-grained porphyritic andesites which have a characteristic platy structure and which are often folded. These belong to a very much earlier period. The writer observed similar bedded and platy andesites in the Mount Popa region, which are the oldest volcanic rocks in that region. The description given by Dr. Coggin Brown agrees in almost every respect with what the author found at Mount Popa. The former writer remarks that their appearance vividly recalls some of the Palaeozoic andesites of Great Britain. But those in the Mount Popa region are definitely post-Peguan in age, as they are seen undoubtedly capping the rocks belonging to the Pegu Series.

Intermediate in age between the older bedded andesites and the black slaggy lavas associated with the vents described above are the massive andesites.

## B. Northern Shan States.

Reference has already been made to the volcano of Loi Han Hun (see Plate XXIII, Fig. 2), a conical hill 3,610 feet above sea-level in the Loi Ling range of the Northern Shan States. It rises to about 700 feet above the surrounding plain, and is situated some six miles to the north-west of Mong Yai, the capital of South Hsenwi State. The rock of which the dome is composed is a dense basalt, almost black in colour with a greenish tinge. A thin section contains phenocrysts of plagioclase, with zonal inclusions of the groundmass, and granular crystals of olivine sometimes fissured and partly converted into serpentine. The groundmass consists of minute lath-shaped crystals of plagioclase felspar and minute greenish-yellow grains of augite with abundant magnetite.

## C. Medaw Island, Mergui Archipelago.

Situated on the same line as the volcanoes of south-west Yunnan and the Shan Plateau is the occurrence of olivine-basalt

in Medaw Island in the Mergui Archipelago. The author visited the area in October 1926 and mapped the geology of Medaw Island in addition to some other islands in the archipelago. Sethu Rama Rao [1] has given a brief description of this occurrence in his memoir on the geology of the Mergui district.

The island of Medaw lies between lat. 11° 40′ and 11° 47′ N. and long. 98° 36′ and 98° 44′ E. in the Mergui district of Lower Burma.

## General Geology.

The western part of the island is occupied by basalt, while the eastern part is formed of the rocks of the Mergui Series. The basalt forms a plateau about 200 feet high, covered with laterite, east of Medaw village. The lava is iron-black in colour and is exposed along the edge of the plateau and in water courses. In places prismatic jointing is very well developed, *e.g.* along the coast at Chaunggyi-wa village, about half a mile west-south-west of Okpo village, near ·20, marked on the one-inch survey of India map. The blocks are polygonal, with four, five and occasionally six sides. When the prismatic blocks are intact they make a picture not unlike that of the Giant's Causeway, Antrim. In some places nodular weathering of individual blocks is to be seen.

The basalt yields a red laterite soil which is overgrown by a dense forest with a very thick undergrowth. The sedimentaries yield a light sandy soil which offers a wide contrast to that of the basalt. The incoming of this almost whitish soil suggests at once the termination of basalt and the presence of the Mergui rocks underneath the soil.

**Olivine-Basalt.**—The basaltic lava is greyish to greenish-black in colour with a very fine texture. In places it is amygdaloidal in character but it is generally compact. It is sometimes bedded. A rock specimen about ½ mile north-west of Gyun Gyun Gyaw, from the stream bank, is very compact and only a few phenocrysts of yellowish olivine can be recognised. Under the microscope a thin section shows a fine texture, and consists of small laths of felspar and colourless crystals of olivine and augite. The

[1] *Mem. Geol. Surv. Ind.*, vol. lv, 1930, p. 19.

felspar, which is mostly oligoclase, is clear, absolutely fresh, and sometimes shows a radiating arrangement and in places is changed to zeolites. Both olivine and augite are colourless, sometimes with idiomorphic outlines, but they often exhibit a rounded or granular appearance. The olivine in a few places is seen to change into greenish serpentine, while augite crystals seem to merge into pinkish-brown glass. Sometimes skeletal crystals of olivine and magnetite are to be seen. Occasional brownish-green crystals with a fairly high refractive index set within crystals of magnetite appears to be picotite.

The groundmass is pinkish-brown, in which granules of magnetite, augite and olivine with a few small laths of felspar are interspersed. Yellowish-brown or greenish-brown palagonite is also present.

Sometimes in the vesicles a greenish fibrous palagonite occurs with yellowish-orange or brownish-yellow borders. It shows a radiating concentric structure. The mineral appears to be chlorophaeite. It has also been observed in the dolerites of the Tharrawaddy area.

It is remarkable that the augite of these basalts is quite colourless, quite unlike the augite of the rocks of central Burma, which is invariably greenish in colour. The felspar, too, seems to contain more alkali than lime. The basalt appears to resemble the mugearite-basalt described from the Kabwet area and is certainly an alkaline type.

**Age.**—Nothing precise can be said about the age of the basalt because its relation to the sedimentary rocks can be studied only at one place, *i.e.* about half a mile west-south-west of Okpo village or about $\frac{3}{4}$ of a mile north-west of Okpomaw marked on the map. The locality is marked ·20 on the map, and it is an isolated hill about 100 feet high. Here the basalt is seen resting on coarse ferruginous conglomerate, the pebbles of which are about an inch in diameter. This conglomerate seems to have weathered into lateritised clay into which the basalt has forced its way. Sethu Rama Rao first noted that a sill of fine-grained olivine-basalt is found in the Mergui Series, and he was of opinion that the basalt is of the same age as the porphyries discovered in a former season by Dr. Heron in some of the outer islands (see *Rec. Geol. Surv. Ind.*, vol. liv, page 52);

but later on it was recorded in the General Report for 1922 (*Rec. Geol. Surv. Ind.*, vol. lv, pt. 1) that the basalt appears to be of Recent age as it was found resting on laterite very similar to that in the valleys of the little Tenasserim and the Ngawun. In the absence of fossils it is very difficult to announce the age of a formation ; however, the author on general grounds believes that the basalt is of late Tertiary or Sub-Recent Age.

## The following Table shows the Order of Igneous Activity in Burma in the Time Scale.

### *Palaeozoic.*

**Northern Shan States.**—Rhyolites and rhyolite tuffs of Bawdwin, Tawng-Peng granite, diorite near Hpalam and olivine-gabbro near Nam Hsan.

**Lagwi Pass, Chinese Frontier.**—Siliceous volcanic tuffs.

**Mergui District.**—Altered acid and basic intrusives.

Quartz-felspar- and granite-porphyry, altered tuffs, volcanic agglomerate, rhyolites, etc., forming some of the islands of the Mergui Archipelago.

### *Late Cretaceous–Early Eocene.*

**Naga Hills.**—Serpentinised lherzolite, dark-green serpentine, hornblende-enstatite-olivine-gabbro with quartz veins in the neighbourhood.

**Kawt-ta Bum.**—Andesitic breccia.

**Mount Loimye.**—Basaltic tuff, basalts and andesites, volcanic breccia with finely laminated ash, andesitic and basaltic breccia.

**Jade Mines Area, Myitkyina District.**—Altered peridotites, dunite, diallage-peridotite, mica-hornblende-peridotite, amphibolite, serpentines, serpentine breccia surrounded by epidiorites and various orthoschists formed by the metamorphism of igneous rocks like gabbros and diorites.

**Manipur Hills.**—Dark-coloured serpentine, gabbro and stratified volcanic ash.

**Minbu and Kyaukpyu Districts.**—Dark-green serpentine with a fine-grained green gabbro. Numerous dykes of dolerite also occur.

**Prome and Thayetmyo Districts.**—Serpentinised saxonites, lherzolites and dunites.

**Henzada and Bassein Districts.**—Altered peridotites, saxonites, lherzolites and dunites. Hornblende-eclogite and hornblende-granulite, microdiorite at the periphery of the peridotitic masses.

**Myaungmya and Bassein Districts.**—White and greenish, fine tuffs and coarse-grained greyish tuffs with boulders of olivine-trachyte and greyish to greyish-black volcanic ashes.

**North Andamans.**—Bronzite-peridotite, serpentines and diorite.

**Middle Andamans.**—Augite-enstatite- and bronzite-peridotites and gabbro. Volcanic ash and tuff of andesitic type. Olivine-basalt and augite-andesite.

**Nicobar Island.**—Serpentine, gabbro and diorite.

**Granitic Intrusions on the East.**—Biotite-granite with hornblende- and tourmaline-granite as varieties. Acid and basic pegmatitic veins, quartz veins, tourmaline-pegmatites.

### *Pliocene.*

**Shwebo District.**—(*a*) Kabwet area: highly altered pillow lava, (*b*) Basic volcanic rocks.

**Lower Chindwin and Myingyan Districts.**—Ash and tuff deposits interbedded with the Irrawaddians.

### *Late Pliocene and Pleistocene.*

**Jade Mines Area.**—Hornblende-andesite and picrite-basalts. Siliceous breccia and agglomerate.

**Lower Chindwin Region.**—Picrite-basalts, olivine-basalts, hypersthene-basalt, tachylyte, nepheline tachylyte, hornblende-andesite, hypersthene-andesite, acid andesite, rhyolite, rhyolite flow breccia, ejected blocks of dolerite, epidorite and

amphibolite, quartz-porphyry, muscovite-porphyry and hornblende-granite-porphyry, peridotites and perknites. Augite-diorite and quartz-diorite, volcanic ashes and tuffs.

**Mount Popa Region.**—Older andesites comprising pyroxene-andesite, augite-biotite-andesite, acid spherulitic andesite and biotite-andesite with hauyne. Silicified tuff and rhyolites. White silicified tuffs and rhyolites, basaltic ashes and tuffs, hornblende-augite-andesite, hornblende-andesite. Olivine-basalt, glassy hypersthene-andesite.

**Prome District.**—Olivine-dolerite.

**Narcondam.**—Hornblende-andesite and agglomerate.

**Barren Island.**—Scoriae, ash, agglomerate and olivine-basalt.

**Shwebo and Mandalay Districts.**—Teschenite, analcite-dolerite, olivine-dolerite, olivine-basalt (mugearite) and tachylyte.

**Thaton District.**—Rhyolites and rhyolite tuffs.

**Teng-Yueh Area, South-west Yunnan.**—Pyroxene-andesite, hornblende-andesite, augite-olivine-andesite and olivine-basalt.

**Loi Han Hun, Northern Shan States.**—Olivine-basalt.

**Medaw Island, Mergui Archipelago.**—Olivine-basalt.

### *Recent.*

**Jade Mines Area.**—Olivine-basalt and siliceous agglomerate.

**Lower Chindwin Region.**—Ashes and tuffs of the explosive craters. Some flows of basalt.

**Mount Popa Region.**—Latest flows of olivine-basalt and andesite, later ashes with bombs of vesuvianite-basalt and andesite.

**Barren Island.**—Active within historic times.

**Teng-Yueh Area.**—Olivine-basalts of She-toe-Shan.

### *Petrogenic Cycles in Burma.*

From the foregoing it would appear that there were four main petrogenic cycles in Burma, which may be listed as follows :

I. Early Palaeozoic, comprising the granite clan, with effusive and hypabyssal representatives.

II. Late Cretaceous-Early Eocene, marking the outbursts of the rocks of the peridotitic and granite clans.

III. Pliocene—pillow lavas, basic volcanic rocks and tuffs.

IV. Late Pliocene, Pleistocene and Recent, comprising predominantly rocks of the basaltic and andesitic clans, with subordinate rhyolites, etc.

# CHAPTER XXXII

## IGNEOUS ACTIVITY (*Continued*)

### I. Variation in Space.

It is interesting to note that the igneous occurrences of Burma show a well-marked variation in space.

Disregarding the few solitary occurrences of igneous rocks of early Palaeozoic age (not precisely determinable) the igneous activity from the late Cretaceous period onwards gives unmistakable evidence of variation in space. As stated earlier, there exist intrusions of peridotitic and allied rocks on the west, while on the east we have the granitic and similar acid intrusions. Both are of about the same age, which ranges from late Cretaceous to early Eocene. It appears in this case that the primary magma separated into its two complementary portions—the femic and the salic. The former erupted on the west and differentiated into various peridotitic rocks with associated gabbros and diorites locally. The acid magma forced its way to the east and formed the granitic intrusions extending from the extreme south of Burma to the Yamethin and Kyaukse districts in the north. It should be noted that the intervening portion, *i.e.* the Central Belt of Burma, was under the sea at the time.

**Central Belt.**—The evidence afforded by the Central Belt is still more interesting, and the variation in space, especially during late Tertiary times, occurs progressively from east to west—in contrast to the west-to-east variation in the late Cretaceous—early Eocene times.

**Jade Mines.**—In the Jade Mines area of the Kamaing subdivision, Myitkyina district, there is very convincing evidence of variation in space of late Pliocene to Recent volcanic rocks from the east to the west. In the east, as described above, picrite-basalt and olivine-basalt occur in the neigh-

bourhood of Namyong. A little to the north, on the same line, occur the hornblende-andesites, hornblende-augite-andesites and trachyandesites. Proceeding farther west we meet the Mabaw siliceous agglomerate. In the neighbourhood, blocks of rhyolite-breccia are found scattered, sometimes in quantity. It appears to the author that the eruptions started in the neighbourhood of Namyong with a very basic magma represented by picrite-basalt. This was followed gradually by normal olivine-basalts, hornblende- and augite-andesites and trachyandesite. Finally, the residue which was of a rhyolitic composition burst through the crust on the west. In brief, the variation proceeding from east to west may be expressed as follows :

> Picrite-basalt→olivine-basalt→hornblende-, and augite-and-hornblende-andesites→trachyandesite→rhyolite and rhyolite breccia and siliceous agglomerate.[1]

**Lower Chindwin.**—Similar testimony is also forthcoming from the Lower Chindwin region. The igneous area can be divided into four quadrants, each with a different rock-group. The eruptions started with a very basic magma (picrite-basalt), forming hills 1,260, 779 and 822. It appears here that, since these occurrences lie mainly on a fault, there was a quiet outwelling of the basic lava. In fact, where the fault terminates there were eruptions of ashes, with blocks of olivine-basalt. Farther north, the magma differentiated into olivine-basalts with tachylytes, nepheline-tachylytes with ashes in places, and forming the hills marked 800 on the one-inch sheet, Okpo Letpan and Natyindaung. In the north-east, the eruptions, which were mostly explosive, built crater walls and ejected blocks of olivine-basalts and hornblende-andesites. On the south-east occur mainly the rhyolites, quartz-, muscovite-, hornblende-granite-porphyry and granite. In general, the decrease in basicity again seems to be from east to west. The derivation of these rocks from two distinct magma types is discussed in the sequel.

**Mount Popa region.**—Similar differentiation in space from

[1] This variation in space must not be confused with the trend of differentiation discussed in the sequel.

east to west is provided by the older volcanic rocks of the Mount Popa region. Here the eruptions started on the extreme east with what have been described as the older andesites. These hills run in a north-west—south-east direction. To the west they pass through biotite-andesites, found in the neighbourhood of Gwegon, to the acid andesites of the Kyaukpadaung region. On the extreme east, though following the same north-east and south-west strike, are found the rhyolites and rhyolite-tuffs of the Kyaukpadaung hills. In brief, the phenomena may be expressed thus :

Pyroxene- and hornblende-andesites→biotite-andesites→ acid andesites→rhyolite and rhyolite-tuffs.

It appears that, with a few exceptions, the igneous occurrences of the Central Belt of Burma show a transition in age from north to south. The northernmost occurrences of Kawt-ta Bum, Mount Loimye and the Wuntho region are of early Tertiary age. Proceeding farther southwards we meet with the igneous occurrences of the Lower Chindwin, Mount Popa and the dolerites of the Pegu Yoma, about the late Tertiary age of which there is no doubt. Farther southwards on the same line, though outside Burma, occur the volcanoes of Narcondam and Barren Island. It is well known that the latter has been active within recent historical times. In this case the most important point to be noticed is that the land along the Central Belt of Burma was gradually extended from the north to the south by the gradual silting up of the Pegu gulf. It seems that, as the land was gradually forming, the manifestation of igneous activity shifted gradually from north to the south. The exception represented by the comparatively recent occurrences in the north in the Jade Mines area of the Myitkyina district are to be noted.

**Shan Plateau and Yunnan.**—The igneous occurrences lying along the edge of the Shan Plateau and on the plateau itself do not yield any conclusive evidence on this point. In Yunnan Coggin Brown and Burton divided the volcanic rocks of the Têng Yüeh district as follows :

(1) *Bedded Andesites* consisting chiefly of fine-grained pyroxene-andesites of a rather acid type.

(2) *Older Lavas*, comprising the massive andesite group, include the following types :

1. Augite-andesite, sometimes amygdaloidal.
2. Olivine-augite-andesite.
3. Olivine-basalt (light-coloured).
4. Enstatite-augite-andesite (pyroxene-andesite).
5. Andesite glasses.
6. Amphibole-andesite, in some cases containing nepheline.

(3) *Newer Lavas*, comprising the basalt lavas of Tay-in-Shan, Ho-shuen-shan and the Kungpo group of volcanic vents.

According to Coggin Brown and Burton very little is known about the field relationships of these lavas, and of the separate flows comprising each group ; but it may be stated that the andesites are older than the basalts, and that the rocks of the first group are the first products of the eruptions.

The field and microscopic characters of these older andesites are not unlike those of the older andesites of the Mount Popa region, and Burton added that " in some outcrops they are distinctly folded and contorted by pressure, but whether there was a great difference in time between their eruption and that of the massive andesites is rather doubtful from the field evidence. Judging from their comparative freshness under the microscope the difference is small and the rocks are most probably Tertiary."

It is again interesting to note that the older andesites occur to the east of the basalts. That is, even in Yunnan in late Tertiary times, the centre of igneous activity shifted from the east to the west, as in other cases cited above. It raises the question whether this east-west shifting of igneous activity in late Tertiary times points to the main thrusts coming from an easterly direction during those times.

## II. Sequence of Eruptivity.

The Palaeozoic igneous occurrences yield no definite evidence as to their eruptive sequence. It is the late Cretaceous—early Eocene rocks which furnish data on these lines. Taking the peridotitic intrusions of the Arakan-Naga ranges we find the following types associated in each area :

(1) **Naga Hills.**—Serpentinised lherzolite, dark green serpentine, hornblende-enstatite-olivine-gabbro. Quartz-veins occur in the neighbourhood.

(2) **Jade Mines Area.**—Serpentinised dunites, mica-, hornblende- and diallage-peridotites, pyroxenites and amphibolites. The rocks are encircled by a crystalline complex consisting of graphite-, glaucophane-, vesuvianite-, hornblende-, chlorite-, kyanite- and quartz-schists, together with igneous rocks ranging from diorites and gabbros to pyroxenites and perknites ; epidiorite derived from gabbro is the commonest type.

(3) **Manipur Hills.**—Dark-coloured serpentine and gabbro.

(4) **Minbu and Kyaukpyu districts.**—Dark green serpentine is associated with a fine-grained green gabbro. Numerous dykes of dolerite also occur.

(5) **Prome and Thayetmyo districts.**—Serpentinised saxonites, lherzolite and dunites.

(6) **Henzada and Bassein districts.**—Altered peridotites, saxonites, lherzolites and pure dunites. Microdiorite occurs at the periphery of the peridotitic masses.

(7) **North Andamans.**—Bronzite-peridotite, serpentines and diorite.

(8) **Middle Andamans.**—Augite-enstatite- and bronzite-peridotites and gabbro.

(9) **Nicobar Island.**—Serpentine, gabbro and diorite.

Coming to the granitic intrusions of the Eastern Hill Ranges we have the following sequence in the Tavoy district :

(1) Biotite-granite, consisting of quartz, orthoclase, acid plagioclase, microcline, biotite with muscovite occurring at the peripheries of the bosses.

(*a*) Acid pegmatite-veins consisting of quartz, felspar and a little biotite.

(*b*) Basic pegmatite-veins. They contain the same minerals as the granite, but with biotite in excess.

(*c*) Quartz veins.

(*d*) Basic intrusions in dykes of rock consisting of hornblende, biotite, quartz, and plagioclase.

(*e*) Tourmaline-pegmatites. The relative ages of (*d*) and (*e*) are not known.

In the Mergui district we have the three varieties of granite :

1. Biotite-granite.
2. Hornblende-granite.
3. Tourmaline-granite.

Later injections into the granite consist of quartz-veins, greisen and pegmatite. Quartz-porphyry also occurs in the area.

**Central Belt.**—Passing next to the Kawtta Bum in the Hukawng valley we have the eruptions of andesitic breccia. In Mount Loimye, however, the following sequence of eruptions was observed :

(1) Black basaltic tuff of aqueous origin interbedded with the older Tertiaries and metamorphised by the intrusion of gabbro.

(2) Flows of basalts and andesites. On the southern spur, which connects Mount Loimye with Chaobadu Bum, at least five distinct flows of lava occur between 3,550 and 3,800 feet above sea-level.

I. Vesicular augite-andesite, about 3,550 ft. level.

II. Doleritic basalt, about 3,550 ft. contour.

III. Porphyritic augite-andesite with phenocrysts of labradorite (glassy and altered), between 3,650–3,700 feet, occupying level ground.

IV. Porphyritic enstatite-basalt, about 3,750 ft. level.

V. Coarse-grained basalt almost approaching dolerite, near 3,800 ft. level.

These readings were taken with an aneroid barometer and are approximate only.

(3) Volcanic breccia with finely-bedded, sometimes laminated, consolidated ash or tuff. On the southern spur, from 4,300 to 3,800 feet, a whitish felspathic tuff was commonly observed.

(4) Andesitic and basaltic breccia building up the dome of Mount Loimye. This marks the most explosive and longest phase.

**Wuntho Area.**—In the Wuntho area the sequence of eruption was as follows :

(1) Volcanic breccia and ash deposits.

(2) Granodiorite.

(3) Tourmaline and other pegmatitic dykes intrusive into (2).

**Lower Chindwin Region.**—According to A. E. Day and V. P. Sondhi the late Tertiary igneous activity in the Lower Chindwin district comprises the following sequence :

(1) The extrusive phase which includes the isolated basaltic tuff deposits at Bambwe and south of Twindaung, the older basalt of the Okkan upland and the rhyolitic extrusions west of Monywa.

(2) The plutonic phase which includes the granites of the Okkan upland and west of Silaungtaung.

(3) The hypabyssal phase comprising the granophyres of the Okkan upland, the quartz-porphyry and mica-hornblende-porphyry east and south of Myayeik.

(4) The latest extrusive phase is represented by the existing crater pits and their ejectamenta, including the Natlabo tuff deposits which rest upon the Pleistocene Plateau Gravel.

Sondhi adds that the olivine-basalt masses, which cut through the Irrawaddian sand-rock, and the older basalt at Silaungtaung, Myethaungdaung, Chindaung and Natyindaung are comparatively fresh and undecomposed, and are much younger than the green basalt of the Okkan upland, but there is no evidence to show how far these basaltic eruptions are connected with the latest or post-Pleistocene period of igneous activity.

**Mount Popa region.**—In the Mount Popa region the sequence of events was :

(1) The eruption of older andesites and the associated tuffs and conglomerates.

(2) The extrusion of Kyaukpadaung lavas and silicified tuffs.

(3) The formation of Taunggni and other white tuffs.

(4) The deposition of the interbedded black tuffs and ashes.

(5) The eruption of the younger andesites and basalts with associated tuffs, agglomerates, and conglomerates.

(6) Later ashes with bombs.

These stages are arranged in descending order ; whence it would appear that when the older andesites and other silicified tuffs were being formed, the enormous mass of Mount Popa did not exist.

The formations (3), (4) and part of (2) appear to be undoubtedly sub-aqueous in origin, and they are distinctly

interbedded with the aqueous Irrawaddian rocks. Some of these rocks themselves show excellent bedding, at times on a very fine scale.

**Barren Island.**—The sequence of eruptivity in Barren Island was as follows :

(1) Eruptions of scoriae, ash and agglomerate.

(2) Ejection of fragmentary scoriae and agglomerate.

(3) Welling out of flows of recent olivine-basalt, andesites, etc.

**Kabwet Area, Shwebo and Mandalay districts.**—In the Kabwet area of the Mandalay and Shwebo districts the sequence of igneous activity is :

(1) Older highly decomposed mottled lava.

(2) Olivine-dolerites, teschenites, etc.

(3) Olivine-basalt (mugearite).

**Teng Yueh Area, Yunnan.**—In the Têng Yüeh area the sequence of eruption, according to Burton, is :

(*a*) Pyroxene-andesites, which in the field were called " bedded andesites " by J. Coggin Brown.

(*b*) Hornblende-andesites, pyroxene-andesites, with augite-olivine-andesites and olivine-basalts. These are the " massive andesites " of Coggin Brown.

(*c*) Olivine-basalts, which in the field were designated " basalt lavas of Tay-in-Shan."

## III. Kindred Suites.

The following kindred suites exist in Burma :

(1) The Bawdwin lavas and tuffs and similar rocks on the Chinese frontier, near the Lagwi pass, and the rhyolitic volcanic rocks of the outer islands of Tenasserim, show a high degree of consanguinity. These rocks are of early Palaeozoic age and form a kindred suite of their own. They are characterised by similar mineral composition, structure and texture, mode of occurrence, alteration and, above all, by similar associated ore-deposits.

(2) The next group is constituted by the serpentinised peridotitic belt of Burma. So close is the petrological similarity that the description of the rocks of one region is applicable word for word to the other. Oldham's remarks in this connection are worthy of reproduction. "The trappean intrusions are confined to the eastern portion of the Tangkul country, and if we except variations in texture, due to unequal rates of cooling, they are substantially all of but one kind. In describing these the words used in the *Manual of Geology* when treating of the serpentine rocks of British Burma may be transcribed almost verbally; the rock . . . is a 'characteristic dark-coloured serpentine; it frequently becomes a gabbro and contains bronzite and is intersected by veins of gold-coloured chrysotile, or sometimes carbonate of magnesia.

"'All this is as true, word for word, of the serpentine of Manipur as that in Pegu and suffices to show the close similarity, if not identity, of the two which in hand-specimens are indistinguishable. A specimen brought from Burma by Theobald might, so far as appearance goes, have been broken off the same block as one brought by me from Manipur.'" The author, having investigated the serpentine rocks of the Henzada and Bassein districts, Jade Mines area and the Hukawng Valley, can further substantiate Oldham's remarks; the rocks are macroscopically and microscopically exactly alike. He had also the opportunity of seeing Ramamirtham's collection of rocks and slides from the Prome and Thayetmyo districts, and these also confirmed the belief expressed above.

Unfortunately, very few chemical analyses of these rocks are available; hence we are not in a position to discuss their consanguinity from a chemical point of view, but the petrological association of the rock-types has already been explained.

(3) The third petrological province is constituted by the granites on the east. It has now been proved that the granites which stretch from the Mergui district in the south to the Kyaukse and Yamethin districts in the north are almost identical in mineral composition, mineral association, etc. The main type is a biotite-granite with modifications containing hornblende, tourmaline and muscovite. These types have been

proved to exist in the Mergui, Tavoy and Amherst districts—in fact, as far north as the granites have yet been traced.

(4) The Wuntho region, in the opinion of the author, constitutes a separate and distinct petrological province.

(5) It is not improbable that the older lava (pillow lava) of the Kabwet area and the basic volcanic rock found interbedded with the Irrawaddians in the Shwebo district, and described above, have a close kinship. It is apparent that these lavas were extruded when the Irrawaddians were being deposited in fresh or brackish water in the geosynclinal Central Belt of Burma, and which attained a huge thickness as a result of subsidence going on *pari passu* with deposition. These rocks were subsequently thrown into folds and uplifted as hill ranges. In the Kabwet area specimens of *Cyrena batissa* were found in the sedimentary rocks occurring in the neighbourhood of highly decomposed pillow lavas.

(6) The volcanic rocks of the Jade Mines area, the Lower Chindwin and Mount Popa, the dolerites of the Prome and Tharrawaddy districts, the volcanic rocks of Narcondam and Barren Islands, the rhyolites, etc., of Thaton district and the olivine-basalts of the Loi Han Hun volcano show marked consanguinity. They are mainly calc-alkaline rocks belonging to the Pacific suite. These occurrences are all connected with folding and, as seen from the table of analyses, pp. 494-496, the rocks are very rich in CaO and MgO and very poor in alkalies. Soda is always in excess of potash.

(7) On the other hand, the olivine-dolerites, teschenites, and mugearite-basalt of the Kabwet area are alkaline in character. These rocks are situated on the edge of the Shan Plateau and form a very distinctive suite. They contain very high percentages of $Na_2O$, $K_2O$, and $TiO_2$ with a low percentage of CaO as contrasted with the rocks of the kindred (6).

## IV. ORIGIN AND HISTORY OF THE IGNEOUS ROCKS

### Trend of Magmatic Differentiation.

Briefly expressed, post-Archaean activity in Burma commenced with the rhyolite and rhyolite tuffs in the neighbourhood of Bawdwin, and similar acid, but plutonic, intrusions of the Tawng-Peng granite in the Northern Shan States. Only a few dykes or minor intrusions of basic rocks have been discovered in the Shan States. Yet siliceous tuffs of the same age as those of Bawdwin also occur in the neighbourhood of the Lagwi Pass on the north-eastern frontier of Burma, and also in some of the outer islands of the Mergui Archipelago. The magma that was erupted in Burma in the early Palaeozoic period was therefore distinctly granitic in character, and this phase of igneous activity was followed by a long and remarkable period of quiescence. It was in the uppermost Cretaceous period, when the land on the east and west was upheaved on the sites of the Shan Plateau and the Arakan-Naga hill ranges respectively, that igneous activity manifested itself in these areas. The Central Belt of Burma was still occupied by a gulf of the sea. On the west a very marked belt of peridotitic rocks, extending from Java and Sumatra through the Andaman and Nicobar Islands to the frontiers of Burma, has been described above. Undoubtedly the igneous activity started here with a very basic magma which, on differentiation, formed types like saxonites, lherzolites, dunites, etc. Gabbro and dolerite have also been found associated with this belt, but forming only minor modifications. At one place in the Henzada district microdiorite was found forming a ring around the periphery of altered peridotites. It appears therefore that the original parent magma differentiated itself as far as diorite, and the residue then consisted of quartz, which is found in the neighbourhood in large quantities in the form of veins and lenses. No granites or syenites have yet been found in this belt. Contemporaneously with the above intrusions, however, volcanic eruptions of ashes, tuffs and trachytic lava took place. The peridotites, etc., were afterwards serpentinised by hydro-

thermal waters containing silica, iron and carbon dioxide in solution.

Across the gulf on the east, and running almost parallel to the peridotitic intrusions, the acid complementary magma was erupted as huge intrusions, building whole mountains of granite which stretch from the Dutch East Indies through Malaya and Lower Burma to the Yamethin and Kyaukse districts and farther north into Upper Burma. This magma had the composition of a sodi-potassic biotite-granite, but modifications like hornblende- and tourmaline-granite are also found. In places tin and tungsten are found associated with them. It is apparent therefore that we have two distinct complementary magmas in the west and the east, but in the north, as in the Myitkyina district, there is an intermingling of conditions: both peridotitic and granitic rocks occur there. Palaeozoic limestone, which is more characteristic of the Shan Plateau on the east, also occurs there.

The trend of the differentiation of the magma in the late Cretaceous—early Eocene times can be stated as follows:

Common Parent

| | |
|---|---|
| Peridotites comprising saxonites, lherzolites, dunites, etc.[1] | Biotite-granite, hornblende-granite, muscovite-granite, tourmaline-granite. |
| ↓ | ↓ |
| Olivine gabbro. | Acid and basic pegmatites. |
| ↓ | ↓ |
| Microdiorite. | Quartz veins. |

The igneous activity later manifested itself in general from north to south, the direction in which the land was gradually formed in the Central Belt of Burma. In the Hukawng Valley explosive sub-aqueous eruptions of andesitic breccia formed the Kawt-ta Bum. Farther south, the Mount Loimye commenced with sub-aqueous basaltic tuffs, which were followed by quiet

[1] Owing to the precipitation of the ferro-magnesian minerals in more than the stoichiometric proportions the magma residuum, as stated above, consisted of quartz only.

outwellings of flows of basalt and andesite, followed in turn by huge and long eruptions of sub-aqueous andesitic breccia and ash, which built the dome of the mountain, 5,124 feet above sea-level.

In the Jade Mines area we have picrite-basalts, olivine-basalts, hornblende- and augite-andesites, trachyandesites and siliceous volcanic agglomerate and breccia. The trend of differentiation in the Jade Mines area can be expressed as follows :

Common Parent

| | |
|---|---|
| Picrite-basalt. | Tholeiitic magma. |
| ↓ | ↓ |
| Olivine-basalt. | Hornblende-andesite, etc. |
| ↓ | ↓ |
| Trachyandesite. | Rhyolite—breccia and siliceous agglomerate. |

Passing on to the Wuntho volcanic region we find that the first igneous activity here was sub-aqueous and deposited fine tuffs and ashes, which were followed by great eruptions of breccia, forming hills like Shinmataung, Pinotaung, etc. In places basalt flows are seen in the stream sections. These rocks have been intruded by a large batholith of granodiorite penetrated by tourmaline-pegmatites and quartz veins.

Next to be considered is the Lower Chindwin igneous region. Here the suite of rocks is one of most varied composition. Rocks ranging from picrite-basalts through olivine- and other basalts, hornblende-hypersthene-andesites and acid andesites to pure rhyolites and rhyolite-flow-breccia occur. Among the plutonic rocks there are ejected blocks of peridotites and perknites, and also masses of augite- and quartz-diorite. Among the hypabyssal representatives there are dolerite blocks with intrusions of quartz-, muscovite- and hornblende-granite-porphyry.

The trend of differentiation in this region seems to support the hypothesis recently advanced by W. Q. Kennedy.[1] The various rock-types have been formed by the differentiation of

[1] *Amer. Journ. Sci.* vol. 25, 1933, p. 239.

two primary magmas: olivine-basalt magma and the tholeiitic-basalt magma as shown below:

Parent Magma

| | |
|---|---|
| Olivine-basalt magma. | Tholeiitic-basalt magma. |
| ↓ | ↓ |
| Picrite-basalt, peridotites and perknites. | Olivine-free hypersthene-basalt. |
| ↓ | ↓ |
| Olivine-basalt (for the various types of olivine-basalt see the original paper [1]), tachylytes and nepheline-tachylyte, basic ashes and tuffs of Twindaung, Leshè, Bambwe and other localities. | Hypersthene-andesite and acid andesite, quartz-diorite. |
| ↓ | ↓ |
| Hornblende-andesites, augite-diorite. | Rhyolite and rhyolite-flow-breccia, quartz-porphyry, muscovite-porphyry, hornblende-granite-porphyry. |

In the Mount Popa region the parent magma was andesitic, and the initial eruptions were sub-aqueous and paroxysmal; they were followed by quiet outwellings of andesitic lava, which differentiated itself into basic pyroxene-andesites, hornblende-andesites, and thence into more acidic flows of andesites in the neighbourhood of Gwegon and Kyaukpadaung. These andesitic lavas were followed by eruptions of rhyolite and rhyolite tuffs forming the hills in the vicinity of Kyaukpadaung. Here also must be included the white and partially silicified tuffs of Taungni, etc. This completes the differentiation of one magma, comprising a single phase of igneous activity. Then followed the eruptions of Mount Popa proper, which started again as paroxysmal manifestations in the form of basaltic tuffs—followed by eruptions of basalts and andesites interbedded with tuffs and agglomerate. Proceeding

[1] *Trans. Min. Geol. Inst. Ind.* vol. xxi, 1927, pp. 192-203.

farther south we meet the simple intrusions of olivine-dolerite in the Prome and Tharrawaddy districts. To the immediate south of Burma, though lying in the same igneous belt, there are the volcanoes of Narcondam and Barren Island. The former is built of hornblende-andesites with subordinate agglomerates.

Barren Island has an outer amphitheatre enclosing a central pile truncated by a small recent crater. The ancient cone is largely built of olivine-basalts interbedded with fragmentary ejectamenta. The central mass is built similarly, and has three distinct flows, the eastern, southern and northern. The physical and geological history of the volcano has been discussed above.

The fissure- and dyke-eruptions of the Kabwet area in the Mandalay and Shwebo districts occur next. It must be understood that the rocks of this area are unique in themselves, being of a distinctly alkaline nature. North of the Irrawaddy river are the intrusive rocks occurring as olivine-dolerites, teschenites and analcite-dolerites. These build both laccolithic intrusions and dykes. South of the river we have the extrusive phase in the form of mugearite-basalts, tachylytes, etc. So here is an instance of an alkaline basaltic magma which came to the surface through fissures on one side, but in the north yielded the hypabyssal representatives, dolerites, but, again, very rich in alkalies. These alkaline rocks may have been formed by the assimilation in depth of the calc-gneisses and limestone of the Mogok Series by basaltic magma. Passing farther south in the Thaton district rhyolites and rhyolite tuffs were erupted along a strike fault. In this area paroxysmal and quiet eruptions of a superheated rhyolitic magma have alternated with one another.

Coming to the Têng Yüeh area in Yunnan there are two phases of igneous activity: (1) an older one constituted by the pyroxene-andesites, which have a bedded character in the field and seem to be comparable with the older andesites of the Mount Popa area; (2) a younger one commencing with andesitic magma, forming hornblende-andesites, pyroxene-andesites, with augite-olivine-andesites. These constitute the "massive andesites" of J. Coggin Brown, followed by a basaltic phase which built up the recent volcanoes of Tay-in-Shan, etc.

Farther south occurred the eruptions of olivine-basalt of Loi Han Hun in the North Hsenwi State of the Northern Shan States and Medaw Island in the Mergui Archipelago. On the whole it appears that the latest eruptions in Burma were mainly of a basaltic character, and from the evidence yielded by the latest extinct volcanoes in Burma, and the still active volcano of Barren Island in the same region, it appears that in Burma we are perhaps living in an age of basaltic eruptions.

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## CHAPTER XXXIII

### VARIATION DIAGRAMS

### Late Cretaceous—Early Eocene Rocks.

No chemical analyses are known to date of the early Palaeozoic igneous rocks of Burma. Of the late Cretaceous—early Eocene peridotitic rocks only two have been analysed chemically, from the Jade Mines area of the Myitkyina district. In the circumstances not much comparison and contrast of the rocks from the different areas can be attempted geochemically.

| | I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|
| $SiO_2$ - | 74·65 | 78·14 | 71·64 | 71·64 | 71·58 | 77·64 | 64·50 |
| $Al_2O_3$ | 13·46 | 12·54 | 14·09 | 14·86 | 12·96 | 11·34 | 15·96 |
| $Fe_2O_3$ | 0·07 | 0·12 | 0·52 | 0·24 | 0·61 | 0·94 | 1·62 |
| $FeO$ - | 0·89 | 0·86 | 2·26 | 2·19 | 3·12 | 1·60 | 3·62 |
| $MgO$ - | 0·38 | 0·12 | 0·04 | 0·18 | 0·35 | 0·00 | 1·58 |
| $CaO$ - | 0·15 | 0·44 | 1·92 | 2·08 | 1·78 | 0·76 | 4·52 |
| $Na_2O$ - | 4·93 | 3·79 | 3·83 | 3·65 | 3·39 | 2·84 | 2·81 |
| $K_2O$ - | 4·65 | 3·20 | 4·68 | 3·91 | 5·03 | 4·52 | 4·10 |
| $TiO_2$ - | trace | nil | 0·42 | 0·41 | 0·66 | trace | 0·64 |
| $P_2O_5$ - | 0·03 | trace | 0·07 | 0·08 | 0·11 | 0·00 | 0·19 |
| $MnO$ - | 0·25 | 0·12 | 0·09 | 0·09 | 0·15 | 0·08 | 0·13 |
| $H_2O+$ | 0·55 | 0·46 | 0·31 | 0·37 | 0·36 | 0·36 | 0·33 |
| $H_2O-$ | nil | nil | 0·26 | 0·25 | 0·12 | 0·28 | 0·20 |
| | 100·01 | 99·79* | 100·13 | 99·95 | 100·22 | 100·36† | 100·20 |

* Contains 0·09 of $MoO_3$ and 0·03 of $BiO_3$.
† Contains 0·10 of fluorine.

I., II. From the vicinity of the 21st mile on the Tavoy-Wagon Road, Tavoy district.
III. Granite, The Gap, Selangor, Malaya.
IV. Granite, Kuala Selangor, Malaya.
V. Granite, Kuala Dipang, Bujang, Melaka, Malaya.
VI. Granite, Gunong Blumut, Johore, Malaya.
VII. Hornblende-granite, Pulao Ubin, Singapore.

**Granites.**—Similarly, only two analyses of the granites of the Tavoy district, detailed opposite, have been published, both by A. W. G. Bleeck.[1] However, they can be compared with similar rock analyses given by J. B. Scrivenor [2] from Malaya.

The first two analyses are of granites from the Tavoy district, where the rock is in direct contact with the wolfram lodes. Unfortunately the data are too limited to admit of any broad generalisations. However, the granites are alkaline in character, bearing fairly high, almost equal, proportions of $Na_2O$ and $K_2O$, though the former is slightly in excess of the latter. The rocks are very rich in $SiO_2$, carrying almost the maximum percentage for granites. Both the CaO and MgO percentages are low. In the Malayan granites III and IV $Na_2O$ is somewhat in excess of $K_2O$; but in V, VI and VII the two alkalies occur almost in equal molecular proportions. The Malayan granites appear to be slightly richer in lime compared with those of the Tavoy district, Burma. The same holds good for FeO and also for the total iron.

## Late Tertiary—Recent Igneous Rocks.

It is of the late Tertiary igneous rocks that thirty analyses, tabulated below, with their localities, are available, of which seventeen analyses are now published for the first time.

[1] *Rec. Geol. Surv. Ind.*, vol. xliii, 1913, p. 19.
[2] *The Geology of Malaya*, Macmillan & Co., 1931.

| | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| | K. 3 | 734 Hill | B. 102 | E. 649 | B.V. 42 | B.V. 4 |
| $SiO_2$ - - | 51·69 | 49·22 | 62·00 | 55·37 | 47·69 | 46·72 |
| $Al_2O_3$ - - | 17·17 | 17·35 | 18·80 | 16·90 | 18·20 | 14·93 |
| $Fe_2O_3$ - - | 2·09 | 2·25 | 2·96 | 5·28 | 5·26 | 5·12 |
| FeO - - | 6·15 | 6·35 | 1·04 | 1·65 | 4·18 | 3·98 |
| MgO - - | 5·53 | 6·07 | 1·00 | 4·61 | 6·02 | 8·70 |
| CaO - - | 6·62 | 7·71 | 4·71 | 5·93 | 11·57 | 12·87 |
| $Na_2O$ - - | 3·91 | 4·47 | 4·27 | 3·58 | 2·74 | 2·12 |
| $K_2O$ - - | 3·15 | 1·51 | 2·31 | 2·34 | 1·39 | 1·45 |
| $H_2O+$ - - | 1·07 | 2·55 | 1·41 | 1·85 | 1·24 | 2·30 |
| $H_2O-$ - - | 0·13 | 0·25 | 0·72 | 0·92 | 0·21 | 0·55 |
| $CO_2$ - - | nil | nil | 0·01 | 0·35 | nil | nil |
| $TiO_2$ - - | 2·13 | 1·46 | 0·41 | 0·40 | 0·80 | 1·10 |
| $P_2O_5$ - - | 0·63 | 0·62 | 0·34 | 0·33 | 0·36 | 0·27 |
| MnO - - | 0·11 | 0·19 | 0·07 | 0·09 | 0·17 | 0·20 |
| BaO - - | 0·05 | 0·03 | 0·15 | 0·21* | 0·08 | 0·08 |
| | 100·43 | 100·03 | 100·20 | 99·81 | 99·91 | 100·39 |

| | VIA | VII | VIII | IX | X | XI |
|---|---|---|---|---|---|---|
| | | B.V. 13 | B.V. 41 | B.V. 58 | | |
| $SiO_2$ - - | 47·10 | 46·26 | 47·28 | 48·16 | 40·77 | 44·66 |
| $Al_2O_3$ - - | 16·32 | 16·68 | 15·28 | 15·52 | 13·22 | 15·14 |
| $Fe_2O_3$ - - | 3·80 | 7·77 | 5·58 | 6·25 | 4·61 | 6·03 |
| FeO - - | 5·00 | 2·41 | 3·93 | 4·10 | 4·30 | 2·50 |
| MgO - - | 11·65 | 5·71 | 9·43 | 8·22 | 15·12 | 10·21 |
| CaO - - | 11·45 | 13·43 | 12·77 | 10·53 | 13·50 | 13·38 |
| $Na_2O$ - - | 1·95 | 3·06 | 2·36 | 2·84 | 3·16 | 4·29 |
| $K_2O$ - - | 0·87 | 1·00 | 1·23 | 0·92 | 1·77 | 1·13 |
| $H_2O+$ - - | 0·50 | 0·59 | 0·61 | 1·39 | 0·48 | 0·32 |
| $H_2O-$ - - | 0·40 | 0·19 | 0·33 | 0·77 | 0·04 | 0·04 |
| $CO_2$ - - | nil | 1·67 | nil | 0·03 | 0·12 | 0·40 |
| $TiO_2$ - - | 0·35 | 1·07 | 0·49 | 0·73 | 2·57 | 1·85 |
| $P_2O_5$ - - | 0·18 | 0·31 | 0·42 | 0·30 | 0·13 | 0·05 |
| MnO - - | 0·25 | 0·16 | 0·18 | 0·16 | 0·08 | 0·09 |
| BaO - - | n.d. | 0·03 | 0·05 | 0·05 | n.d. | n.d. |
| | 99·82 | 100·34 | 99·94 | 99·97 | 99·87 | 100·09 |

* Contains 0·07 of SrO.

| | XII | XIII | XIV | XV | XVI | XVII |
|---|---|---|---|---|---|---|
| | | | | P.S. 10 | P. 399 | P. 13 |
| $SiO_2$ | 44·83 | 74·95 | 56·98 | 49·40 | 47·40 | 51·83 |
| $Al_2O_3$ | 8·82 | 12·04 | 18·24 | 20·35 | 21·80 | 17·73 |
| $Fe_2O_3$ | 2·56 | 0·24 | 2·82 | 10·25 | 10·05 | 3·82 |
| FeO | 3·14 | 2·54 | 3·55 | | | 4·16 |
| MgO | 18·00 | 0·77 | 3·98 | 4·78 | 5·68 | 5·70 |
| CaO | 13·81 | 0·50 | 8·48 | 12·10 | 12·25 | 10·44 |
| | 2·15 | 3·11 | 2·69 | 2·50 | 1·96 | 2·87 |
| $K_2O$ | 3·72 | 3·66 | 2·55 | 1·06 | 1·08 | 1·21 |
| $H_2O$ + | 1·34 | 2·08 | 0·33 | n.d. | n.d. | 0·74 |
| $H_2O$ – | 0·02 | n.d. | n.d. | n.d. | n.d. | 0·04 |
| $CO_2$ | 0·43 | n.d. | n.d. | n.d. | n.d. | nil |
| $TiO_2$ | 1·06 | 0·25 | 0·47 | n.d. | n.d. | 0·83 |
| $P_2O_5$ | 0·12 | n.d. | n.d. | n.d. | n.d. | 0·21 |
| MnO | 0·07 | n.d. | 0·23 | n.d. | n.d. | 0·14 |
| BaO | | n.d. | n.d. | n.d. | n.d. | 0·08 |
| | 100·07 | 00·14 | 100·30 | 100·24 | 100·22 | 99·80 |

| | XVIII | XIX | XX | XXI | XXII | XXIII |
|---|---|---|---|---|---|---|
| | | . 82 | P.S. 7 | P. 300 | M. 4 | |
| $SiO_2$ | 58·10 | | 54·21 | 49·07 | 48·00 | 49·70 |
| $Al_2O_3$ | 17 30 | 17·48 | 18·48 | 17·11 | 18·70 | 18·04 |
| $Fe_2O_3$ | 7·20 | 2·93 | 6·06 | 5·10 | 3·08 | 2·10 |
| FeO | | 0·53 | 1·16 | 3·29 | 4·29 | 4·92 |
| MgO | 3·15 | 0·85 | 4·02 | 6·43 | 8·30 | 7·65 |
| CaO | 7·40 | 3·61 | 8·08 | 10·72 | 8·80 | 9·50 |
| | 2·22 | 4·15 | 2·98 | 2·79 | 2·00 | 3·90 |
| | 1·62 | 3·70 | 2·44 | 1·95 | 0·72 | 1·35 |
| 2 | 1·90 | 1·72 | 1·21 | 1·68 | 3·70 | 1·80 |
| $H_2O$ – | | 0·17 | 0·44 | 0·81 | 1·70 | 0·10 |
| $CO_2$ | n.d. | nil | nil | 0·17 | nil | nil |
| $TiO_2$ | n.d. | 0·26 | 0·58 | 0·52 | 0·30 | 0·45 |
| $P_2O_5$ | n.d. | 0·33 | 0·33 | 0·45 | 0·10 | 0·29 |
| MnO | ·30 | 0·03 | 0·13 | 0·18 | 0·20 | 0·20 |
| BaO | ·25 | 0·12 | 0·14 | 0·08 | n.d. | n.d. |
| | 99·44 | 100·34 | 100·26 | 100·35 | 99·89 | 100·00 |

| | XXIV | XXV | XXVI | XXVII | XXVIII | XXIX |
|---|---|---|---|---|---|---|
| | 6/659 | 6/664 | 6,673 | 6/666 | 6/701 | 6/703 |
| $SiO_2$ - - | 52·97 | 53·72 | 53·57 | 49·07 | 61·31 | 61·24 |
| $Al_2O_3$ - - | 19·18 | 18·14 | 16·22 | 17·04 | 16·80 | 16·86 |
| $Fe_2O_3$ - - | 3·15 | 2·66 | 1·80 | 4·77 | 3·73 | 3·97 |
| FeO - - | 4·20 | 4·95 | 7·54 | 4·71 | 1·60 | 1·41 |
| MgO - - | 2·88 | 3·31 | 3·89 | 8·34 | 3·06 | 3·07 |
| CaO - - | 10·68 | 9·79 | 8·61 | 11·46 | 6·86 | 6·62 |
| $Na_2O$ - - | 2·88 | 3·41 | 3·97 | 2·16 | 3·21 | 3·23 |
| $K_2O$ - - | 0·50 | 0·91 | 0·64 | 0·65 | 1·84 | 2·11 |
| $H_2O+$ - - | 1·00 | 0·44 | 0·93 | 0·07 | 0·26 | 0·11 |
| $H_2O-$ - - | 0·03 | 0·08 | 0·04 | 0·08 | 0·06 | 0·09 |
| $CO_2$ - - | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| $TiO_2$ - - | 1·94 | 2·74 | 2·70 | 1·85 | 1·66 | 1·60 |
| $P_2O_5$ - - | 0·27 | 0·19 | 0·22 | 0·08 | 0·14 | 0·13 |
| MnO - - | 0·11 | 0·08 | 0·12 | 0·09 | 0·09 | 0·09 |
| BaO - - | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| | 99·79 | 100·42 | 100·25 | 100·57 | 100·62 | 100·53 |

### Kabwet Area

I. Mugearite, Kabwet area, Mandalay district (Analyst, T. Marrack).

II. Teschenite, Nattaung, 734 Hill, Kabwet area, Shwebo district (Analyst, T. Marrack).

### Jade Mines Area

III. Trachyandesite, Jade Mines area, Myitkyina district (Analyst, T. Marrack).

IV. Hornblende-andesite, half-mile north-east of Ngagahtawng, Kamaing sub-division, Myitkyina district (Analyst, A. W. Groves).

### Lower Chindwin Region

V. Olivine-basalt, Twindaung crater, Lower Chindwin region (Analyst, T. Marrack).

VI. Olivine-basalt, Thazi Hill, Lower Chindwin region (Analyst, T. Marrack).

VIA. Picrite-basalt, Kyaukkadaung, Lower Chindwin region (Analyst, W. H. Herdsman).

VII. Olivine-basalt, Okpo Hill, Lower Chindwin region—decomposed (Analyst, T. Marrack).

VIII. Olivine-basalt, Taungbyauk, Lower Chindwin region (Analyst, T. Marrack).

IX. Olivine-basalt, Natyindaung, Lower Chindwin region (Analyst, T. Marrack).

X. Pyroxene-hornblendite (ejected block), Wunbo, Lower Chindwin (Analyst, S. Parker).

XI. Olivine-plagioclase-basalt, Twinywa Crater, Lower Chindwin (Analyst, S. Parker).

XII. Biotite-pyroxenite (ejected block), Wunbo, Lower Chindwin (Analyst, S. Parker).

XIII. Mica-liparite from Kyaukmyet (Analyst, F. Hinden *in* P. Kelterborn), Lower Chindwin Region.

XIV. Augite-hornblende-andesite from Twinywa Crater (Analyst, N. Sahlbom *in* P. Kelterborn), Lower Chindwin region.

MOUNT POPA REGION

XV. Olivine-basalt, near the northern end of the Eastern flow, and about 25 feet below its top, Mount Popa region.

XVI. Iddingsite-basalt, from near Legyi village, Popa Road, Mount Popa region.

XVII. Vesuvianite-basalt (bomb), Mount Popa region (Analyst, T. Marrack).

XVIII. Augite-hornblende-andesite (older) about 2 miles south of Shawdaw, Mount Popa area (Analyst, Messrs. D. Waldie & Co., Calcutta).

XIX. Biotite-andesite (older), Mount Popa region (Analyst, T. Marrack).

XX. Hornblende-andesite, Ngayangon flow, Mount Popa region (Analyst, T. Marrack).

XXI. Hornblende-augite-andesite, Taunggala, Mount Popa region (Analyst, T. Marrack).

DOLERITES OF PROME AND THARRAWADDY DISTRICTS

XXII. Olivine-dolerite, Biyandi Myenettaung, Prome area (Analyst, W. H. Herdsman).

XXIII. Olivine-dolerite, Tharrawaddy area (Analyst, W. H. Herdsman).

BARREN AND NARCONDAM ISLANDS

XXIV. Augite-andesite, west-north-west of Central Cone, south of point 632, Barren Island (Analyst, H. S. Washington).

XXV. Augite-andesite, 100 yards north-east of landing place, Barren Island (Analyst, H. S. Washington).

XXVI. Augite-andesite, Bay one-half mile south-west of landing place, Barren Island (Analyst, H. S. Washington).

XXVII. Basalt, Coast near north point of island, Barren Island (Analyst, H. S. Washington).

XXVIII. Hornblende-dacite, Summit Narcondam Island (Analyst, H. S. Washington).

XXIX. Hornblende-dacite, north side, 1400 feet above sea-level, Narcondam (Analyst, H. S. Washington).

The variation diagrams adopted for a graphical comparison of the analyses are of the type in which silica percentages are plotted as abscissae and the other oxides as ordinates. First the variation diagrams for the Lower Chindwin, Mount Popa and Barren Island and Narcondam are plotted separately.

**Lower Chindwin Region.**—The variation diagrams of the rock types from the Lower Chindwin region are plotted for the oxides, $Al_2O_3$, $Fe_2O_3$ plus FeO, FeO, MgO, CaO, $Na_2O$, $K_2O$ and $TiO_2$ in Fig. 33. The rock types Nos. X and XII representing pyroxene-hornblendite and biotite-pyroxenite respectively, occurring as ejected blocks, stand out by themselves. The picrite-basalt, VIa, from Kyaukkadaung seems to be a member of a kindred different from the rest. It is low both in $K_2O$ and $Na_2O$, containing the lowest percentages of the alkalies for this region. It is also low in CaO and $TiO_2$. But, on the other hand, it possesses high FeO and MgO. The low alkalies but high FeO and MgO are more appropriate to a rock with a lower $SiO_2$ percentage. It therefore seems that perhaps by contamination with the Irrawaddian and Pegu sandstones the silica percentage of this rock has been raised ; but, on the other hand, an addition of early-formed olivine crystals to basaltic magma would also account for these anomalies.

On the whole it appears that there is more than one kindred represented in the Lower Chindwin lavas. For instance, the picrite-basalt from Kyaukkadaung seems to represent ankaramite, while the remaining basalts with varying amounts of nepheline in the norm have affinities with the pacificite of T. Barth.[1]

**Mount Popa Region.**—The variation diagrams for the Mount Popa region are shown in Fig. 34. In this case the analyses

[1] *Journ. Washington Acad. Sci.*, vol. xx, 1930, p. 60. See also Shand, S. J., *Q.J.G.S.*, vol. lxxxix, 1933, p. 5.

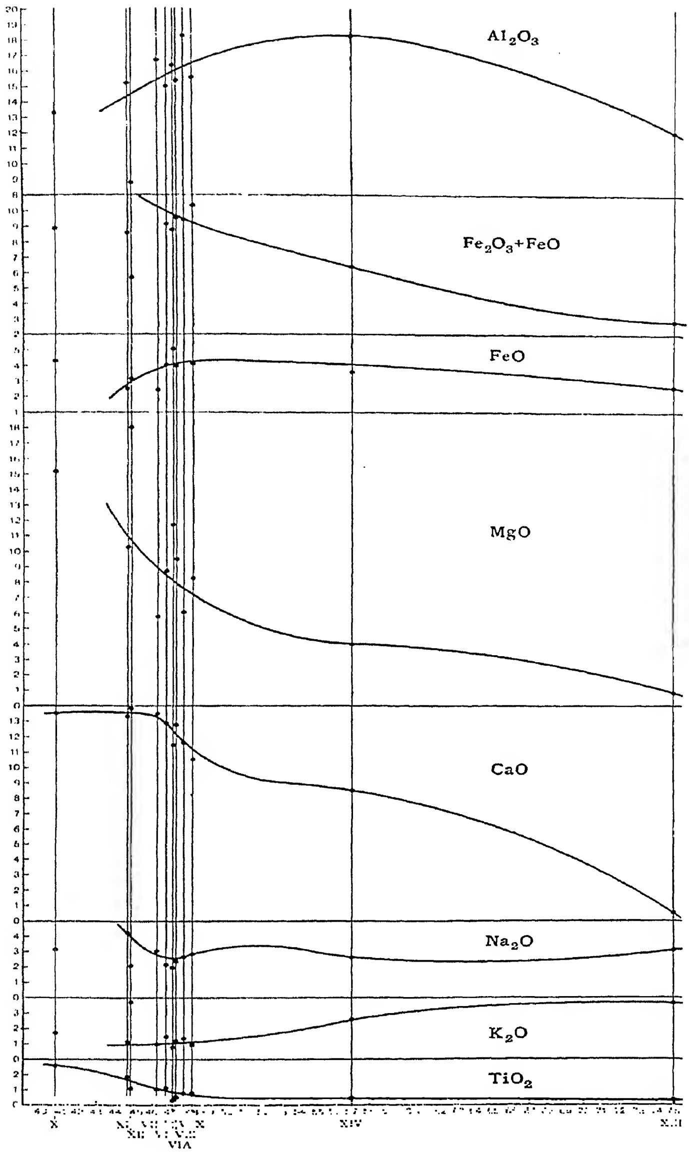


FIG. 33.—Variation diagram of the igneous rocks of the Lower Chindwin region.

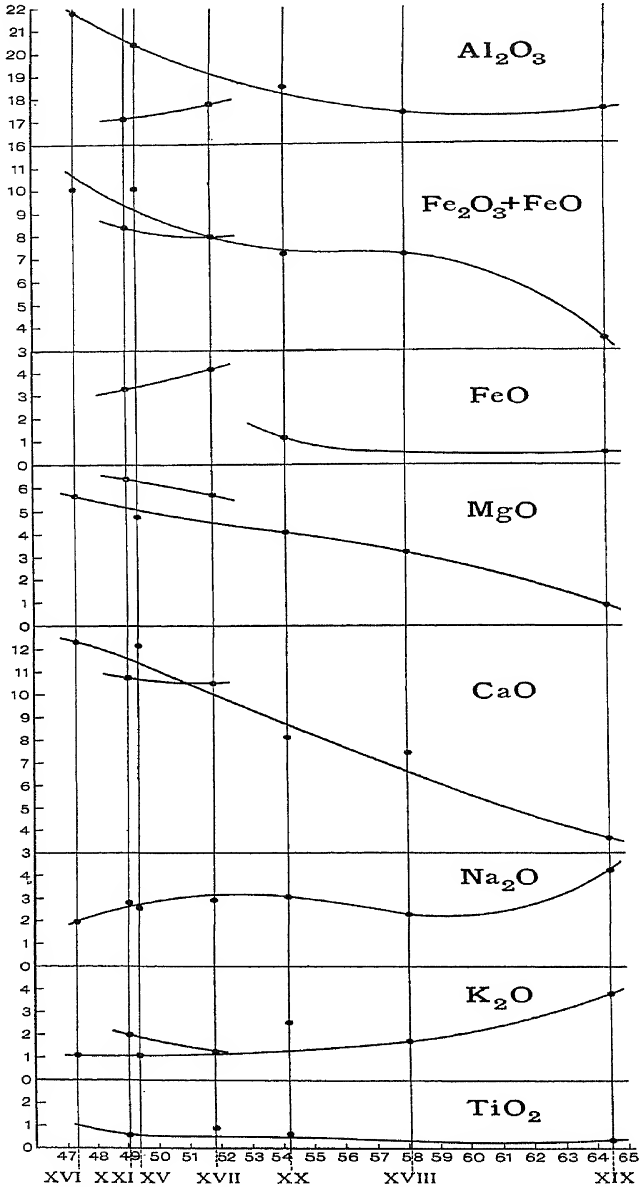


FIG. 34.—Showing the variation diagram of the igneous rocks of the Mount Popa district.

which do not fit the curves are XVII and XXI. The vesuvianite-basalt bomb, XVII, is richer in CaO and MgO, and the magma may have assimilated some of the underlying magnesian limestone of the Pegu Series before it was actually thrown out in an explosive eruption. It is correspondingly low in FeO and $Al_2O_3$. No. XXI is a hornblende-augite-andesite which has also probably been contaminated under deep-seated conditions again by dolomitic limestone, with the result that it is high in MgO and low in $Al_2O_3$ and iron. It is also high in potash, which property it shares in common with some of the andesites from the Lower Chindwin region, the Jade Mines area and Barren Island (see Fig. 36).

With the exception of the $Al_2O_3$ curve the forms of the remaining oxide-curves are comparable with those of typical calc-alkaline assemblages as depicted by Harker[1] in his figures 20 and 29.

**Narcondam and Barren Islands.**—The variation diagrams for Narcondam and

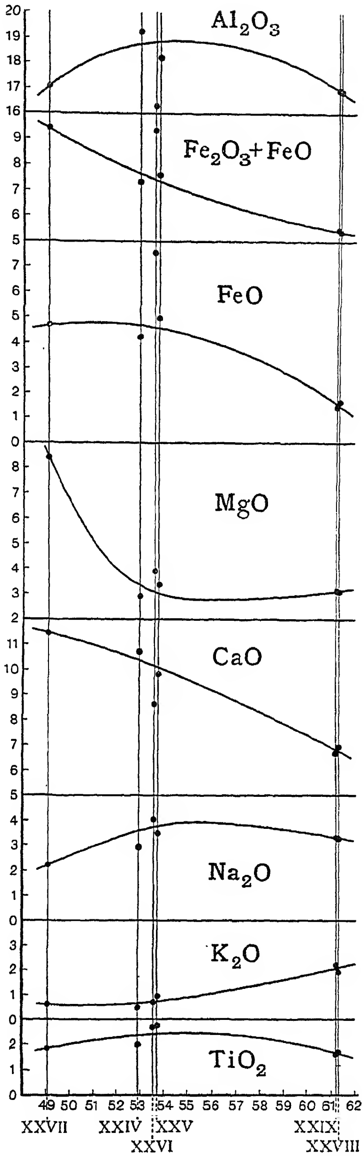


FIG. 35.—Variation diagram of the lavas of Barren Island and Narcondam.

[1] *Natural History of Igneous Rocks*, Methuen, 1909, pp. 126 and 129.

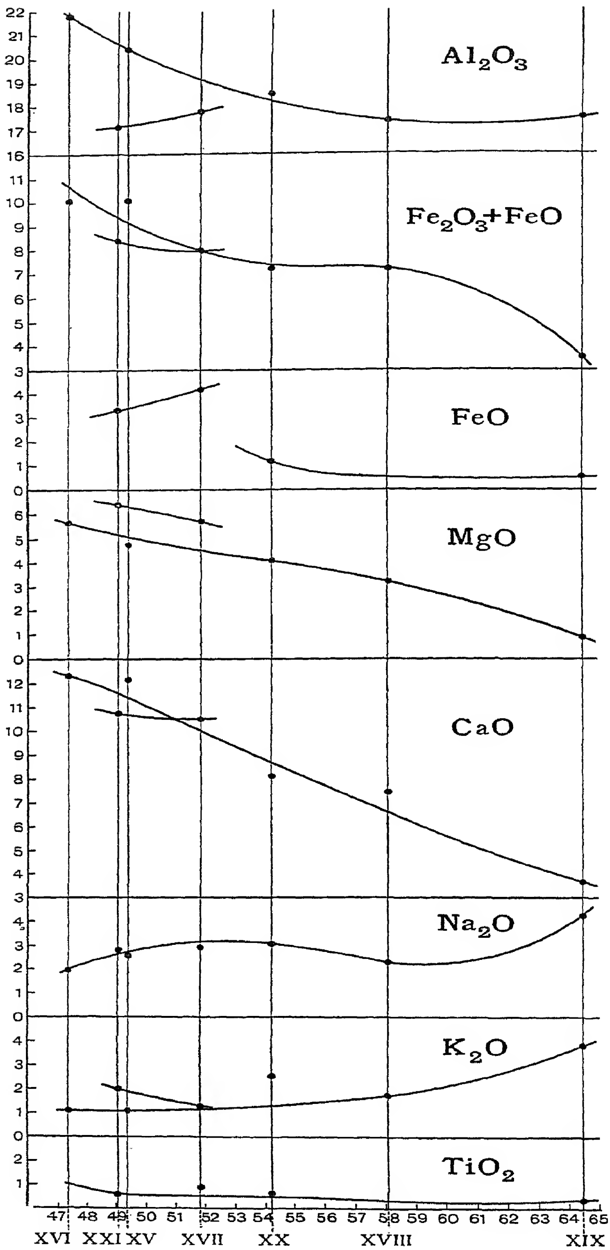


FIG. 34.—Showing the variation diagram of the igneous rocks of the Mount Popa district.

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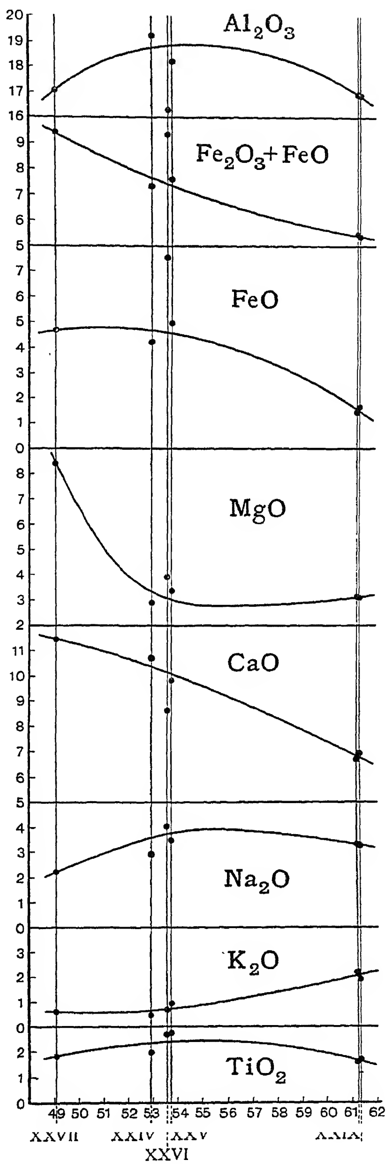


FIG. 35.—Variation diagram of the lavas of Barren Island and Narcondam.

[1] *Natural History of Igneous Rocks*, Methuen, 1909, pp. 126 and 129.

Barren Islands are depicted in Fig. 35. The rocks, XXIV, XXV, XXVII, XXVIII, and XXIX form a comagmatic suite ; the augite-andesite No. XXVI, is, however, very high in FeO and low in CaO, but the total amount of iron present is equal to that of the basalt, XXVII. These anomalies may well be due to alteration as seen in the Lower Chindwin lavas.

## Variation Curve for Burma and Narcondam and Barren Islands.

In Fig. 36 the analyses of the late Tertiary igneous rocks of Burma, Barren Island and Narcondam, are plotted, all the available analyses from all localities being used. The rocks are approximately of the same age, at least they are the products of the same igneous cycle, and it would be reasonable to expect that the points representing rocks from one area would prove to be complementary to those of other districts, and the whole assemblage of points would lie on, or reasonably near to, a series of curves of normal shape. Actually this is not true in all cases, and evidence of genetic linkage suggested by one series of curves is, in some cases, not confirmed by others. Viewed thus, all the curves are not equally helpful ; but it would be unreasonable to expect the several series to differ to a significant extent for all the component oxides : there is bound to be overlap in respect of some, and anomalies in other cases.

**The Titania Curves.**—One of the most instructive series of curves shows variation in the $TiO_2$ content of the rocks. The total range is from 0·3 to 2·7 per cent., and the fact that rocks from different areas (but with approximately the same percentage of $SiO_2$) contain such widely different amounts as 0·5 and 1·9 per cent. of $TiO_2$ clearly demonstrates that at least two series are represented. Actually, as shown in Fig. 36, all the points fall on, or reasonably close to, three curves : one, concave downwards, includes the Lower Chindwin rocks, those from the Jade Mines area, Mount Popa and the Tharrawaddy and Prome districts. By contrast, the rocks from the Barren Island and Narcondam, south of Burma, fall on a second curve, convex upwards and lying well above the first.

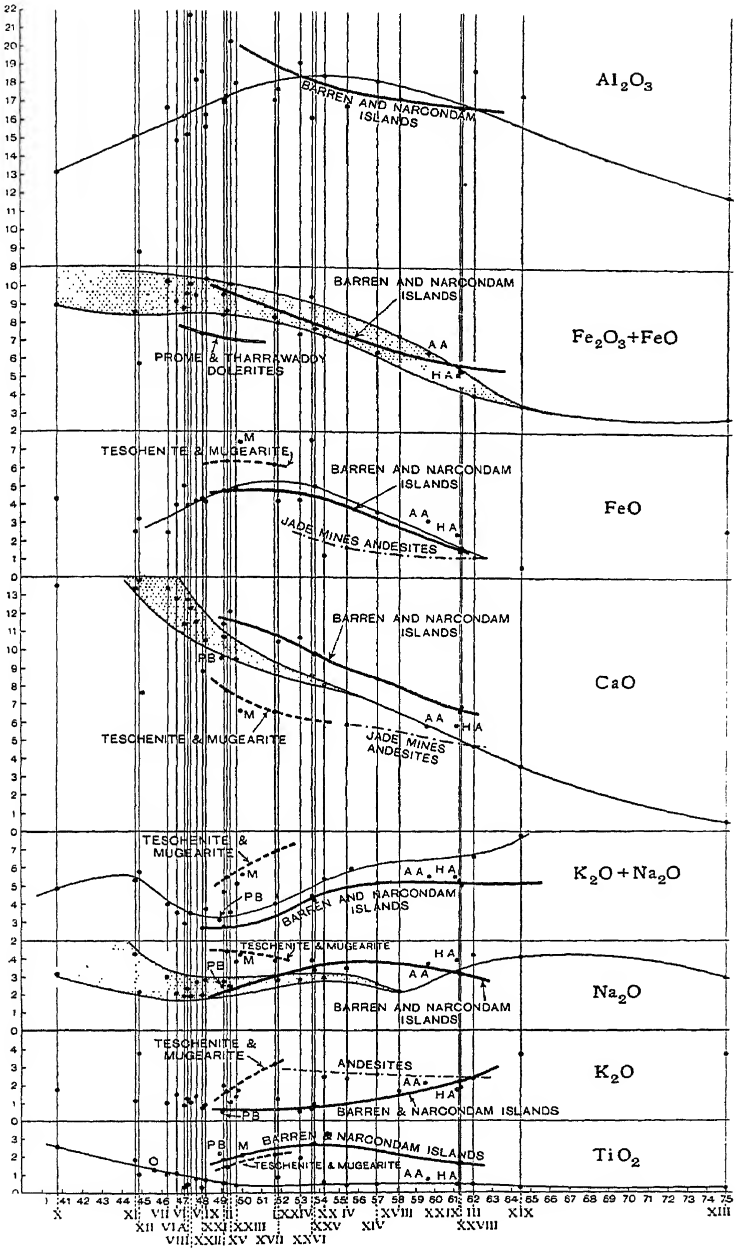


FIG. 36.—Variation diagrams of late-Tertiary igneous rocks of Burma, Barren Island and Narcondam.

Although this curve might be so modified as to include also the mugearite and teschenite from the edge of the Shan plateau (Kabwet area), one is justified from facts brought out by the other curves in regarding them as forming a third distinct series.

It is interesting to note that "oceanite" (Daly's average) lies exactly on the Chindwin-Popa curve, and that the same author's "all andesite" and "hornblende (amphibole) andesite" also lie on this line. These points are indicated by the letters "O," "AA" and "HA" respectively on Fig. 36. On the other hand, the rocks covering the same silica percentage from Narcondam and Barren Is. are definitely well above average in respect of $TiO_2$. Another of Daly's averages, that for "Plateau Basalt," falls very close to the Barren Island–Narcondam series.

**The Potash Curve.**—Confirmation of the genetic linkages suggested by the curves just considered is afforded by those for potash. For their silica percentages the rocks of the Barren Island–Narcondam suite are uniformly low in potash, this being notably the case with the andesites, which average less than one per cent. By way of contrast, the andesites from the Jade Mines, the Lower Chindwin (Twinywa) and Mount Popa (Taunggala) are all closely connected in their richness in potash, and these points lie on a smooth curve quite distinct from that for the other rock types from the same area and from the Barren Island–Narcondam suite. There is again exact coincidence between one of the Barren Island basalts and Daly's average "Plateau basalt."

**The Soda and Total-Alkalies Curves.**—The outstanding fact demonstrated by the soda curves is the distinctive nature of the mugearite and teschenite from the Shan Plateau edge. From general principles this might well have been expected; but it will be noted that, in respect of their soda content, the rocks of the Chindwin-Popa belt merge with those of the Islands: neither series is distinctive in respect of soda.

The isolation of the mugearite-teschenite series is still more evident on the total-alkalies curves; while the same curves indicate a divergence between the Chindwin-Popa suite and the Barren Island–Narcondam series, as the silica percentage

increases. Both suites are rather different from the averages : the plateau basalt point falling equidistantly between the two, and this is also the case with the " all andesite " average.

**The Lime Curve.**—As suggested above, certain of the curves afford evidence of linkage that is not consistent with deductions drawn from the other curves. This is well illustrated by the lime curves. At first sight it looks as if the points group themselves about three lines : one marking the upper limit, another the lower limit of lime variation, while the third occurs between the other two. They are not, of course, the only lines that might be drawn ; but they are the most obvious ones. The smoothest curve includes olivine-basalt (No. XII), Lower Chindwin, biotite-pyroxenite (No. XII), Lower Chindwin, olivine-dolerite (No. XXII), Prome area, the mugearite and teschenite from the Kabwet area (Nos. I and II) and the hornblende-andesite and trachyandesite (Nos. IV and III) from the Jade Mines area. The inference is that the Kabwet rocks are genetically related to the Chindwin-Jade Mines rocks ; but this is completely at variance with the evidence afforded by the curves for $TiO_2$, $K_2O$, $Na_2O$, total alkalies, and the coincidence must be fortuitous. Evidently any conclusions must be based upon careful examination of all the curves.

**General Conclusions.**—From a study of all the curves it is evident that the rocks from the margin of the Shan Plateau are representatives of a suite genetically different from the others. Further, the rocks of the Jade Mines area are closely related to those from the Lower Chindwin area, and these, in turn, with the Mount Popa rocks. The Jade Mines rocks appear to be more closely related to the andesites from Mount Popa than to their nearer neighbours from Chindwin ; but such conclusions are rather unsound as the number of analyses is small. However, the regularity with which No. XIX, the older biotite-andesite from Mount Popa, falls on the curves that include the two analysed rocks from the Jade Mines area is significant and cannot be accidental. The vesuvianite-basalt bomb, which was noted as an exception in the Mount Popa suite, again falls outside the main curves. The magnesia of basalts from Okpo (VII) and Natyindaung (IX) is anomalous, perhaps due to alteration.

With regard to the dolerites from Prome and Tharrawady the evidence is difficult to evaluate. In respect of total iron they form a series of their own, being very deficient compared with other basic rocks of Burma. In respect of soda and total alkalies the Tharrawady olivine-dolerite appears comparable

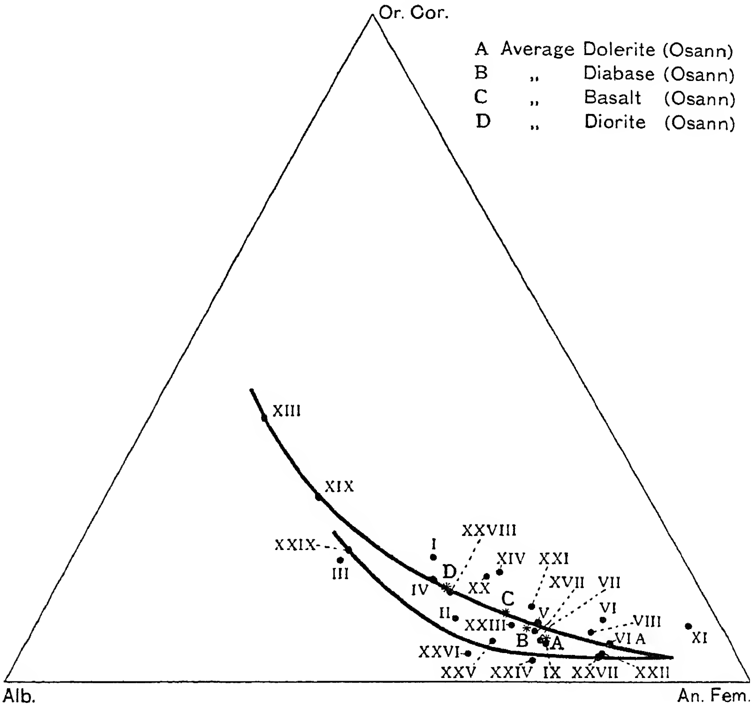


FIG. 37.—Diagram showing norm composition (excluding quartz and nepheline) of late-Tertiary igneous rocks of Burma, Narcondam and Barren Island.

with the alkali rocks (teschenite and mugearite) of the Kabwet area. In most respects it falls into line with the Chindwin-Popa suite. It differs from the mugearite-teschenite series notably in FeO and TiO. The Barren Island–Narcondam suite, as shown above, do form a distinct series of their own in almost all respects and present a strong contrast with the other series of Burma. This fact is substantiated by a study of the norm composition of these rocks, depicted in Fig. 37. In this connection their geographical position, as

oceanic islands in the Bay of Bengal, is doubtless significant. As shown above, the volcanoes of these islands lie on a continuation of the igneous line connected with the Central Belt of Burma. There is no evidence of any significant difference in tectonic history between different parts of this belt, and the magmatic differences referred to above must be due to some cause other than those of a tectonic nature. Farther to the north on the mainland rhyolites and granites are abundantly developed, and the series is typical of continental areas ; but in the islands the only quartz-bearing rocks are the dacites, and even in these the quartz is normative only. In the islands the series consist of basalts, augite-andesites and hornblende dacites, *i.e.* of rocks normally occurring in oceanic islands.

Fig. 37 shows the norm composition (excluding quartz and nepheline) of the late Tertiary and Recent igneous rocks of Burma, Narcondam and Barren Island. Their relations with regard to the average dolerite, diabase, basalt and average diorite are also shown. The consanguinity of the Lower Chindwin and Mount Popa rocks, as suggested also by Fig. 36, is evident, while the Narcondam and Barren Island rocks fall in a different province, and the curve formed by joining the points representing rocks from these oceanic islands branches from the main curve which appears to be normal for the epicontinental types.

# CHAPTER XXXIV

## GEOTECTONICS OF BURMA

Brief references to the tectonic history of Burma have already been made, especially in Chapters I, X and XXI, and the relationships of the igneous activity of Burma to that history have been discussed in Chapter XXVI. It now remains to present a brief summary of the main tectonic features of the country.

### Early Palaeozoic Movements.

After the formation of the Archaean gneisses, which formed the nucleus of Burma and which are now exposed in the Katha and other districts of Burma farther south, deposition under fresh-water conditions proceeded, and later the land represented by the Chaung Magyi Series was thrown into highly acute folds and subjected to denudation. It is believed by La Touche, on account of the absence of conglomerates and the fineness of the succeeding fossiliferous sediments, that the old land before being submerged had been worn down to a peneplain but little raised above the sea-level of that epoch ; and that, when submergence took place, the sea swept over a very large area in such a manner that the new coastline was situated at a considerable distance from that portion of the sea-floor on which the fine-grained beds that now exist were deposited. After some lapse of time the land was submerged again during Ordovician times in a tranquil and rather shallow sea with an uneven floor, and the resulting deposition lasted until the period of the Namhsim Stage, when local emergence appears to have occurred.

**Permo-Triassic Break.**—With the commencement of Devonian time submergence took place over a wide area once more and continued until the end of the Permian, when a general

diastrophic break occurred, as observed in the Shan States between the Upper Plateau Limestones and the Napeng beds of Rhaetic age, and, in Lower Burma, between them and the Upper Triassic strata. This submergence during Upper Triassic times is believed to have been but local.

**The Mesozoic Geosynclinals.**—Burma, west of the Shan Plateau, is believed to have formed part of the ancient Gondwana continent, and the shore line ran along its western boundary. After the Permo-Triassic break sedimentation was resumed in two distinct geosynclinal areas, one marking the site of the present Shan Plateau and its southern continuation into the Karenni hills and Tenasserim, and the other representing the present Arakan-Naga region. This latter geosyncline is believed to have been an arm of the Pacific, where the undoubted Triassic and Cretaceous strata of Arakan and Assam were deposited. This sea may or may not have been connected to the remnants of the Ancient Tethys, which then covered a great part of Tibet, the northern frontier of Assam, the Shillong Plateau and the region east of the Shan States. Testimony is now available that strata of Triassic to Cretaceous age are present in both these regions. The basin covering the present Shan Plateau had its continuation into Yunnan and China, while the Arakan-Naga geosyncline extended into Assam, and there is little doubt that the land separating the two seas existed in the north, forming part of the present Myitkyina district.

### Emergence of Shan Plateau and Arakan Yoma.

Towards the close of the Cretaceous period and the beginning of the Tertiary era great diastrophic movements occurred in Burma, and these apparently coincided with some of the world-wide epeirogenic movements then happening elsewhere. Gondwanaland, which once extended not only from India to Burma but also from South Africa to Australia, broke up at this time. These movements were accompanied by widespread manifestations of igneous activity in Burma, as discussed in the foregoing pages, and had their counterpart in India proper. At this time both the geosynclinals commenced to rise into mountain masses accompanied by sinking of the land, which later constituted the

Burmese and the Assamese Gulfs. The Himalayan and the Burmese movements appear to have gone on almost simultaneously. The former operated from north to south, while the latter acted mostly from east to west. On the east the mountains of the Shan Plateau and its continuation to the south were formed, while on the west the Arakan-Naga ranges were uplifted. The axis of the latter was most probably initiated in Nummulitic or possibly towards the close of Negrais times. The Shan Plateau is traversed by several faults which have not yet attained isostatic equilibrium. On the west the Arakan-Naga mountains constitute a very tightly compressed anticlinorium with several subordinate folds.

**Boundary Faults.**—Since that period both these regions have remained land masses, and the limits of the Shan Plateau on the west and the Arakan-Naga mountains on the east are determined by great boundary faults in each case. On the east the boundary fault separates the Archaean, Palaeozoic and Mesozoic deposits of the Shan Plateau from the Tertiary deposits of the Central Belt, while the boundary fault on the west separates the Mesozoic deposits of the Arakan-Naga region from the Tertiaries.

## Geotectonics of Shan Plateau.

La Touche is of the opinion that the Shan Plateau has been affected by two series of compressive forces. The first caused the formation of more or less regular folds, accompanied by overthrusts or reversed faults parallel to the strike of the folds, and the second comprises the vertical faults caused by the sagging of the underlying Archaean floor. These latter faults have no relation to the direction of the strike of the rocks, but follow straight or slightly curved lines and are often at right angles to each other. They are frequently visible at the surface as long lines of vertical scarp.

The north-to-south folding of the mountains of the Shan Plateau is seen in its older Palaeozoic rocks, while the Plateau Limestones, being massive, have only been broken by a series of parallel faults, most of which are shown on Plate XXV. La Touche compared these fractures to the Dinaric type of faulting. The Lilu overthrust which runs parallel to the

Nam-Tu from Panghsa-pye to the north has been described in Chapter XIV. This fault dies away immediately opposite the point where the boundary of the Chaung Magyi Series, or, in other words, the contour of the old land surface, bends from a general north-south direction to the west.

The folds of the Namyau Series and the Plateau Limestones strike north-north-west and south-south-east, so that there now exists a somewhat regular series of parallel bands, modified by subsequent faulting and partly removed by denudation.

**Dislocations in the Eastern Ranges.**—In the Eastern Ranges of the Northern Shan States, the dislocations take the form of more or less elongated domes, usually with a core of the more ancient rocks that constitute the floor of the Palaeozoic sea. There is a considerable variation in the direction of their longer axes, and in their shape and size, evidently due to the occurrence of these old rocks. Thus the Loi-Len range and others to the north of it trend east and west, but with a tendency at their western ends to veer round towards the south-west. The longer axis of the dome-shaped mass of Hwe Mawng and the Silurian strata to the east of Loi Ling, on the other hand, run north and south; and this is also the direction of the ranges east of Mong-Yai, much modified by faulting, and of the folds along the eastern flanks of the Loi Pan-Loi Twan range.

**Structure of Loi Pan-Loi Twan Range.**—The structure of the Loi Pan-Loi Twan range, as unravelled by La Touche, appears to be that of a huge dome faulted in a direction transverse to the longer axis across the centre, so that the southern half of it is alone visible (see Plate XXV). The core of Chaung Magyi rocks is very broad at the northern end, but gradually narrows, until to the south of Loi Twang it disappears entirely. The fossiliferous Palaeozoic rocks along the eastern flanks form one limb of a huge anticlinal arch, the western limb of which has been concealed by faulting. Reference to Plate XXV shows that the belt of fossiliferous rocks to the north, between Mong La and Pinghsai (not marked on the maps), is very broad and is partly repeated by a minor fold on the Nam-hen, but to the south of Pinghsai it becomes very narrow and compressed, and near Hwe Mawng, there are indications of inversion of the strata.

mass and the late Tertiary deposits of this region, which may be partly of Pleistocene age, were deposited in already existing river valleys and were folded in post-Tertiary times. The geological record of this region is very incomplete, nevertheless there is evidence of three movements, viz., (1) in the early Triassic, (2) in the late Cretaceous—early Eocene, and (3) in the post-Tertiary.

## Geotectonics of the Arakan-Naga Hills.

It will have been gathered already that the earliest fossiliferous formation partaking in the constitution of the Arakan-Naga hills is of Triassic age, and it is believed that the late Permian—early Triassic movements, which we have seen affected the Shan States, caused the subsidence of these hills also, and their occupation by an arm of the sea. It is not certain whether deposition went on continuously until Cretaceous times. It has, however, now been proved beyond doubt that the Arakan-Naga hills formed a long, narrow peninsula in lower Eocene times, as a conglomerate band indicating an ancient coastline has been found at the base of the Eocene in several places. Near Saw in the Pakokku district, a limestone associated with it contains *Orthophragmina* and small nummulites. Below this horizon Cotter found Cretaceous fossils, *e.g.*, *Exogyra*, *Nerinea*, *Orbitoides*, proving thereby that the conglomerate is basal Eocene in age. During the whole of Tertiary times these hills formed a continually rising geanticline as contrasted with the almost continuously sinking geosyncline of the Central Belt or the Irrawaddy basin. In the Pakokku district conglomerates are frequently intercalated in the Eocene, proving the proximity of a coastline, whilst the Pegus of that district are a fresh-water or estuarine formation. In the Minbu district conglomerates are common in the Pegu beds, especially in the north. To the south of Minbu, the Irrawaddy Series is composed of gravels, while the Pegu Series is of a more marine type than in the north of the district. These facts indicate clearly the gradual retreat of the sea to the south. Another noteworthy point is that there is invariably a steadily decreasing dip, proceeding away from the Yoma and reaching deposits higher and higher in the geological

scale. From this Cotter concludes that when deposition was proceeding in the middle of the geosyncline, the strata near the margins were probably acquiring a slight dip eastwards, through earth-movements uplifting the Arakan-Naga hills.

### Tertiary Geosyncline or Burmese Gulf.

With the beginning of the Tertiary era the result of the upheaval of land masses both on the east and west was the sinking of the land bounded by faults on either side, and the centre of deposition shifted to what constitutes at present the Central Belt of Burma. During Eocene, Oligocene and up to Mid-Miocene times, this area was a very important geosyncline, where strata with a thickness of several thousands of feet were laid down. This geosyncline has been referred to as the Burmese Gulf above and its history has been discussed in Chapter XXI.

**Uplift of Central Belt.**—The movements proceeded continuously, with occasional periods of interruption, and caused sufficient subsidence to permit of a huge thickness of strata being accumulated. During, but mainly towards the end of the Pliocene period this geosyncline was uplifted into the Central Belt of Burma, including the Pegu Yoma and its continuation into the hill ranges farther north, by movements again operating from east to west. This region has been thrown into anticlinal and synclinal folds, which in places are broken up by faulting.

**Structural Lines in Central Belt.**—The most important feature to be noticed about the tectonics of Burma is a system of more or less north-to-south folds which have been apparently produced by lateral movements operating from east to west, as is shown by the way in which the wave fronts have been disturbed and deflected by the Himalayan movements which proceeded from north to south. The structural lines of Burma follow a somewhat sinuous course in the south, but, as mentioned by Sir Edwin Pascoe, they veer round northwards from a north-west—south-east direction in Thayetmyo, to north-north-west to south-south-east (Yenangyaung), they approach a more or less north-south direction (Yenangyat) and in the Lower Chindwin district lie a little east of north to a little west of south. Farther north still there is a still further deflection towards the

east, increasing until the hills of Assam join those of the Himalaya system. At this angle of mutual interference, the direction of the structural lines is east-north-east—west-south-west veering locally to east-west. This movement evidently kept pace with the Himalayan one and probably commenced in early Tertiary times. Recently G. W. Lepper [1] of the Burmah Oil Company has summarized the tectonics of the Central Belt. The general strike of the folds in the Tertiary Central Belt is roughly parallel to the trend of the mountain ranges on the east and west, *i.e.*, usually within 15°–20°, east or west of north and south. According to Lepper one of the most striking features of the geological structure is the persistence of the main synclinal area which may be traced southwards from west of the Indaw anticline in latitude 24° and across the Chindwin river. It continues through the Pakokku district in longitude 94° 30′ to the Thayetmyo district. In the former district it broadens out to separate the Yenangyat-Singu-Yenangyaung and Minbu anticlines from the Pegu Series bordering the Arakan-Yoma. This large syncline attains its maximum development west of the Yenangyaung and Singu-Lanywa-Yenangyat oil fields. In the Thayetmyo district, however, it narrows down and becomes split up by anticlinal folds striking north-north-west—south-south-east. Farther south, faulted anticlines and some small synclinal basins intervene between the main longitudinal syncline and the pre-Tertiary rocks. East of the anticlines of the central oilfields, which border the main syncline on its east side, many other folds occur and this is especially true in the region between latitude 20° and 22°, north of the Pegu Yoma (see Chapter XXIII).

## Age of the Folds of the Central Belt.

It is agreed now that some folds in the Irrawaddy basin are of earlier age than others. For instance the Pondaung range, which is 200 miles long and rises to a height of over 4000 feet, is pre-Irrawaddian and perhaps even of lower Tertiary age, as in the Maw Valley near Tilin there are deposits of gently dipping Upper Maw Gravels, a local facies of the Irrawaddians, resting

[1] *Proceedings of the World Petroleum Congress*, 1933.

upon the upturned edges of the Lower Eocene with strong unconformity and discordance. This proves that the Pondaung fold is much older than the Maw Gravels.

The folds of Yenangyaung, Yenangyat-Singu and Minbu do not appear to be of an age earlier than the Irrawaddians as the latter are seen vertical or overhanging all along the eastern boundary of the Pegu outcrop at Yenangyat and appear to have undergone as much disturbance as the Pegu Series lying underneath. Besides, this parallelism of dip is also visible at Yenangyaung and Minbu. From this it is reasonable to assume that the Pegu beds were horizontal and undisturbed at the time when the Irrawaddians were being deposited on them. The Pagan-Gwegyo-Nashandaung fold appears to be mainly post-Irrawaddian in age, though there is some doubtful evidence of contemporaneous erosion in the south.

## Evidences of Recent Upheaval.

It has already been noted that unmistakable evidence exists of the recent uplift of land in the form of the raised beaches of the Arakan coast and the Andaman Islands. The Plateau Gravels are a Pleistocene formation containing palaeolithic implements at Yenangyaung. These gravels occur on the east bank of the Irrawaddy near Yenangyaung, Singu, etc., at a height of three hundred feet or more above the present river level. Similarly on either side of the Yaw river in the Pakokku district boulders and gravel beds are seen some three hundred feet above the present river level. In fact every stream in the Pakokku and Minbu districts is flanked by belts of old raised river gravels. Similarly in the north the Uru river in places is surrounded by the Uru Boulder Conglomerate to a height of about 1000 feet or more and the Tanai *Hka* in the Hukawng valley has similar raised boulder conglomerates skirting it. Both these formations of Pleistocene to sub-Recent age are found tilted at an average angle of 10°, thus confirming their recent upheaval.

There is no doubt that the river gradients during the Pleistocene period were much steeper and the river currents more rapid than at the present day. In the Kamaing Subdivision of

the Myitkyina district some of the boulders of Pleistocene age measure about five feet in diameter, which is certainly beyond the capacity of the present streams to transport them. Cotter has noted similar instances in the Pakokku district.[1]

But evidence of recent uplift is not confined to the Plateau Gravels and the older alluvium alone. The streams are beginning to cut down and erode the newer alluvium. Instances of this are to be seen in several parts of Burma.

It has been adduced above that the delta of the Irrawaddy has also undergone a recent uplift.

## Comparison of the Himalayas with the Burmese Mountains.

In conclusion it may be added that so far it has been customary to regard the mountains of the Shan States to the Himalayas and the Central Belt as the foredeep equivalent of the Indo-Gangetic trough. The analogy seems to be fairly true, but the author wishes to add that the conditions in Burma are duplicated. The Arakan-Naga hills are again of the same age as the Himalayan mountains and those of the Shan States, and are also bounded by a trough on the west represented by the old Assamese Gulf.

## Tectonic Phases.

Important orogenic periods which were accompanied by igneous activity have been mentioned in Chapter XXVII, but here the important diastrophic phases which have been responsible for the tectonic features that are observed in Burma to-day are recapitulated.

(1) Early Palaeozoic. The age of this orogenic period cannot be fixed with certainty but it may have coincided with pre-Ordovician to very early Ordovician times.

(2) Late Permian—early Triassic. In Chapter XXVII it was not found possible to assign any igneous activity exactly to this phase; but if the Mergui Series is ultimately found to both over- and underlie the Moulmein Limestones, then some of the igneous

[1] *Journ. and Proc. Asiat. Soc. Beng.*, vol. xiv, 1918, p. 419.

activity of Tenasserim was manifested, as in Malaya, at this time.

(3) Late-Cretaceous—early Eocene. This was the most important orogenic phase in the tectonic history of Burma. It upheaved the mountains of the Shan States with their southern continuation and also those of the Arakan-Naga region.

(4) Post-Eocene. These movements lifted higher the existing mountains of Burma.

(5) Pliocene.
(6) Pleistocene.} These movements brought about the uplift of the Central Belt of Burma.

(7) Recent and sub-Recent. Finally, movements of Recent date have given Burma its present shape.

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# APPENDIX A

## NOTE ON THE CORRELATION OF THE GEOLOGY OF BURMA AND MALAYA

BY

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It has been my privilege to read Dr. Chhibber's valuable addition to regional geology while still in the press, and the author has asked me to contribute some remarks on the correlation of the geology of Malaya with that of the much larger area he has dealt with farther north. Owing to the admirable clearness with which Dr. Chhibber has presented his information and conclusions this is not a difficult task, although we cannot say yet that the correlation is perfect. It is, however, very encouraging to find that now the work of the Geological Survey Department in Malaya accords, in the main outlines at least, not only with the work of colleagues in the Netherlands East Indies, but also with the work of those in Burma.

The country described by Dr. Chhibber is separated from Malaya by a narrow strip of Lower Siam, about two hundred and fifty miles from north to south, a distance equal roughly to that separating the Langkawi Islands from Port Swettenham and much less than the distance from the Langkawi Islands to Singapore.

About the geology of this intervening portion of Lower Siam little has been published. I have received information from the Siamese Mines Department in Bangkok and also from Dr. Wilhelm Credner of Kiel University when my guest in Malaya, all of which indicates, as one would expect, that the rocks of this area are a continuation of those in Malaya. There is, however, one very important piece of published palaeontological information, namely the description of fossils found at Kuan Sim Loh in Patalung, about fifty miles north of the border of Perlis, one of the Unfederated States of Malaya. These were first described by the late Professor McKenny

Hughes as Permo-Carboniferous (*Report of the British Association*, Glasgow, 1901, p. 414), but later by Dr. F. R. Cowper Reed (*Geol. Mag.*, 1920) as a "Culm" or Lower Carboniferous fauna. The rock in which these fossils occur resembles rock found below Carboniferous limestone in the Langkawi Islands. It is siliceous, not perfectly fresh, and fine-grained.

In comparing the rocks of Malaya and Burma we can begin with one evident correlation: the Moulmein Carboniferous limestones and the Carboniferous limestones of the Malay Peninsula (part of what was formerly called the "Raub Series") are of the same period, and in Malaya we have a Viséan fauna described by Dr. Stanley Smith (see *Geology of Malaya*, 1931, p. 56). Thus the Carboniferous limestones of Sumatra, recently reported rocks with Carboniferous fossils in Dutch Borneo, the Malayan Carboniferous, the Carboniferous of Indo-China, and the Carboniferous of Burma, can be regarded as detached outcrops of one great system. I will not attempt to discuss possible Permian rocks here, but may perhaps say that however much one may wish to abolish the Permian system altogether, it is impossible to ignore the wonderful collections described as Permian from the Timor-Ceram islands (H. A. Brouwer, *Geology of the Netherlands East Indies*, 1925, pp. 14-17).

In Malaya and the Netherlands East Indies no stratified rocks older than Carboniferous have been proved by palaeontological evidence to outcrop; but in both areas there is evidence of a granite older than Carboniferous. In Burma, on the other hand, Ordovician, Silurian, and Devonian rocks are known. That the presence of rocks older than Carboniferous may be proved at some future date in the Malay Peninsula or Archipelago is of course by no means impossible: both areas contain rocks that in days gone by would have been described as "ancient schists," and which indeed were in one case regarded as Archaean in the Archipelago until Jurassic fossils were found in them; but as far as Malaya is concerned no schists are known whose ancient appearance cannot be attributed to metamorphism by a late Cretaceous granite.

Nevertheless there is one great question about a series in Lower Burma, which may be older than Carboniferous, and its correlative in Malaya: what is the age of the apparently unfossiliferous Mergui Series, and by what is it represented in Malaya?

Until I read Dr. Chhibber's book I must confess to a pessimistic feeling about ever arriving at a correlation of the Mergui Series with anything in Malaya or the Netherlands East Indies because there was an inclination to regard it as pre-Cambrian on petrological grounds, and there is no evidence whatever of pre-Cambrian beds among the rocks on the same line of strike in Sumatra.

To begin with, Dr. Chhibber puts one doubtful point at rest. Once it appeared possible that the Mergui Series might be represented in Malaya by something either above or below the Carboniferous limestone. Now Dr. Chhibber says definitely that the Mergui Series is below the Moulmein Limestone, therefore it cannot be equivalent to our Trias, which, moreover, is characterised by widespread radiolarian cherts, not mentioned as occurring in the Mergui Series. Further, Dr. Chhibber considers that the Mergui Series lies conformably under Moulmein Limestone in at least one place, the valley of Ngawun, but one such exposure of course does not prove the presence of a general conformity.

I have never seen the Mergui Series in the field, but just before leaving Malaya in 1931 I was able to send a Malay assistant to collect specimens in the country near Victoria Point, the southernmost part of Burma. The specimens he brought back showed signs of metamorphism by the granite of that locality and contained no fossils ; but if they had been collected in the Langkawi Islands, where there are magnificent cliff-sections of the Carboniferous and perhaps the Trias, they would have been referred to a thick series of sedimentary rocks, shale and quartzite, with obscure fossil remains on one small island, and thin bands of impure limestone lying conformably under the Carboniferous limestone. The conformity is obvious in cliff-sections.

These Langkawi rocks are found also on the adjacent mainland in Perlis and Kedah, conformable under the Carboniferous limestone ; and although it is not yet proved I have little doubt that the fossiliferous " Culm " rock in Patalung is on the same horizon. In Perlis they have yielded fossils described by R. B. Newton as late Carboniferous or Permo-Carboniferous (*Annals and Mag. of Natural History*, ser. 9, vol. xvii, pp. 49-64, 1926). The matrix is a partially calcareous quartzite and the presence of *Fusulina* led to the determination of age as late Carboniferous or Permo-Carboniferous ; but it is well to remember that the Patalung fossils were first described as Permo-Carboniferous. This difficulty is discussed in *The Geology of Malaya*, pp. 56 and 57.

Petrologically Dr. Chhibber's description of the Mergui Series accords with these rocks in the Langkawi Islands, which are the nearest islands under British influence off the coast of Malaya to Victoria Point ; but I suspect that I should call Dr. Chhibber's " greywackes " tuffs of the Pahang Volcanic Series.

Dr. Chhibber mentions as members of the Mergui Series carbonaceous argillites that yield a blackish soil. Such carbonaceous rocks are of common occurrence in the Malayan Carboniferous, but similar rocks are also found in the Trias.

With so very limited first-hand knowledge of these rocks it is of course impossible to give a definite opinion about the correlation of the Mergui Series; but after reading Dr. Chhibber's description it seems at least probable that it is a northern extension of the beds below the Carboniferous limestone in the Langkawi Islands and on the adjacent mainland, and therefore probably part of the Carboniferous succession.

The chief difference between the Trias of Burma and Malaya is that Burma has Triassic limestones whereas none has been proved to exist in Malaya. On the other hand, Triassic limestones are known in the Netherlands East Indies. The Napeng Beds of Burma have yielded undoubted Rhaetic fossils, described by Miss M. Healey, and R. B. Newton described two collections of fossils as Rhaetic in Malaya, but these determinations have been queried by Dr. J. Weir (*Geol. Mag.*, 1925, pp. 347-350) because of the absence of *Avicula* (*Pteria*) *contorta*, the typical Rhaetic fossil which is present in the Napeng Beds, but there is no doubt that the Malayan beds are Triassic.

With regard to the Jurassic and Cretaceous rocks of Burma, these find their counterparts in the Netherlands East Indies and in Sarawak, but in Malaya (*i.e.* that part of the Malay Peninsula under British control) there is only one doubtful determination of Jurassic rocks and no Cretaceous fossils have been found. In both Burma and Malaya, however, and in the Netherlands East Indies, there is a series of rocks younger than the Moulmein Limestone, and the only point I propose to discuss here in addition to the foregoing is that Dr. Chhibber thinks that there was a big break in sedimentation between the Permian and the Rhaetic, and there appears to be some evidence of an unconformity in the field, although he says that the apparent unconformity of the Napeng Beds over Plateau Limestone may be due to solution of the limestone underneath. In Malaya this solution of limestone under the Trias is a great handicap to anyone attempting to determine whether or no there is an unconformity between the Trias and the Carboniferous limestone (with which Permian may be included), and the most that I can say is that I have not yet seen a section in the field enabling one to be sure that an unconformity exists. In Sumatra, however, a clear, conformable succession has been found with *Fusulina* limestone at one end and a rich Upper Triassic fauna at the other. The conglomerates of the Malayan Trias show abundant evidence of unimportant unconformities along a shore-line, but south of Burma there is no good evidence known to me of an important break separating the Trias from underlying rocks. The rocks

above the limestone in the Langkawi Islands that have been mapped as Trias are conformable to the limestone, but they have no fossils and may be Carboniferous. Dr. Chhibber's opinion regarding the Burmese succession is very interesting.

As neither Eocene, Oligocene, nor Pliocene rocks are known in Malaya, while Miocene rocks are very doubtful, the only other bedded Burmese rocks to be considered here are the late Tertiaries of Amherst, Mergui, and Tavoy, which, judging from Dr. Chhibber's description, bear so close a resemblance to the small patches of coal-bearing beds with oil-shales in Perlis, Perak, and Selangor, that I have little doubt they are all lacustrine deposits of approximately the same age. The Malayan beds were first tentatively classed as Miocene because of the similarity of the coal to coal believed to be Miocene in the Netherlands East Indies; but it is now known that these beds may be of much later age. Dr. Chhibber thinks that the Burmese beds may be of late Tertiary or even Pleistocene age. There is a possibility of the Malayan beds being even post-Pleistocene, when the sea-level was higher than now, but the compactness of the shales, and the oil, which is small in quantity, are against that view.

An unfossiliferous limestone in the Perak occurrence of these beds may have been formed in an arm of the sea extending up the present Perak River valley, or it may be a fresh-water lacustrine limestone like those mentioned by Dr. Chhibber.

A very coarse conglomerate in the Selangor patch, excellently exposed in railway-cuttings, is a counterpart of the coarse conglomerates mentioned by Dr. Chhibber.

Beds similar to these late Tertiary or Pleistocene beds in Burma and Malaya are said to occur in the part of Lower Siam between the two countries.

Passing on now to the igneous rocks, in Malaya and the Netherlands East Indies there is evidence of a pre-Carboniferous granite, a late Cretaceous granite accompanied by strong folding, and a later post-Miocene period of folding with newly discovered granite of this very youthful age in Sumatra and West Java. It is therefore refreshing to anyone like myself, whose views on the age of the Malayan granite masses have not been accepted in every quarter, although the evidence is conclusive, to find that Dr. Chhibber describes a granitic magma irrupted in Burma during early Palaeozoic times, then a long and remarkable period of quiescence followed by great earth-movements and irruptions of more granite in late Cretaceous to early Eocene times, and lastly a post-Pliocene folding

(the reader should remember that in the eastern part of the Netherlands East Indies there is evidence of folding in progress in our own times).

In Burma Dr. Chhibber distinguishes a broad differentiation of the late Cretaceous, early Eocene magma, affording on the west peridotite, olivine-gabbro, and microdiorite; on the east biotite-, hornblende-, muscovite-, and tourmaline-granites, acid and basic pegmatites, and quartz-veins. It is this eastern portion of the magma, with some outcrops of serpentine, that has been continued into the Malay Peninsula. In Lower Burma, Malaya, Singkep, Banka, Billiton and parts of Sumatra, the more acid granite of this magma is the source of the famous, rich deposits of tin and tungsten. It might be remarked here that evidence for a late Cretaceous to early Eocene mineralization in Asia is growing: it was evidently a period of great importance for present-day economics.

The age of certain serpentine-outcrops in Malaya has long been a puzzle. They are probably the same age as those mentioned by Dr. Chhibber in lower Burma, *i.e.* late Cretaceous, early Eocene; but it is possible that some of the Malayan serpentine is derived from basic rocks of the Pahang Volcanic Series, ranging from Carboniferous to Trias, which is evidently represented in Lower Burma and farther north as well as in the Netherlands East Indies, telling us of a long period of violent and widespread vulcanicity in ancient times in the same area where a more restricted vulcanicity is in progress now.

In Malaya hornblende-granite becomes more abundant as one passes from west to east. This is even noticeable in so small an area as Singapore Island where acid granite is found on the west, hornblende-granite and quartz-mica-diorite, both cut by interesting dyke-rocks including lamprophyres, on the east. There does not appear to be such a differentiation of rocks of the same age in Burma, but Dr. Chhibber mentions lamprophyres. In Malaya there is now good evidence that the newly solidified granite was first invaded by dolerite, hornblende-porphyry, hornblende-granophyre, quartz-biotite-gabbro, quartz-norite, vogesite and spessartite, and that later it was again invaded by acid vein-rocks.

It would be possible to write a great deal more about the bearing that Dr. Chhibber's book has on Malayan geology but space does not permit. Let me conclude by saying that all geologists who have worked in Malaya are under a deep debt of gratitude to the author; and we must hope that it will not be long before the intervening Siamese territory is surveyed so that we may have a continuous geological map of Burma, the Malay Peninsula and the Malay Archipelago.

# APPENDIX B

## NOTE ON THE CORRELATION OF THE GEOLOGY OF BURMA AND ASSAM

BY

P. Evans, B.A., F.G.S., A.M.Inst.P.T.

The province of Assam lies immediately north-west of Burma, and as the two provinces meet along a line several hundred miles in length it might be expected that the geological features would have much in common. Although there are indeed many points of resemblance, there are also many striking contrasts, and the detailed correlation of the earth-movements and stratigraphical sequence of the two provinces has not yet been worked out. The dividing line between Assam and Burma corresponds roughly with the central line of the hills stretching from the Arakan Yoma to the Patkais ; the geological unit on the Assam side of the hills extends across the provincial boundary into south-eastern Bengal and even beyond into the narrow coastal strip of Arakan.

The geology of the crystalline rocks of Assam has not yet received the amount of attention given to the oldest rocks of Burma, and although a large area of gneisses and intrusive rocks occupies a considerable part of the Shillong Plateau, and schists comprise a great portion of the Eastern Himalayas, it is not yet possible to make any close comparison between the metamorphic rocks of the two provinces.

The contrast between Burma and Assam is shown by the difference in the development of the Palaeozoic beds. In Assam, the whole geological range between the ancient crystalline rocks and the Cretaceous has only three known representatives : boulders of Lower *Productus* Limestone have been recorded in the Eastern Himalayas ; shales, sandstones and basalts probably of Damuda age occur in the Abor Hills ; and the Sylhet Trap has been regarded as Jurassic. There is nothing as yet known comparable with the full record of the Palaeozoic and Mesozoic eras found in the eastern part of Burma.

From Cretaceous times onwards, the Assam record is much fuller and the type of sediment deposited was very similar in the two countries ; even here there is an important difference, the Assam

rocks, with few exceptions, being devoid of fossils, whereas the Burmese Tertiaries have an abundant fauna. The Cretaceous deposits of the Garo and Khasi and Jaintia Hills in Assam are shallow-water beds —conglomerates, sandstones, thin coals. The fauna is not abundant but shows that the Assam Cretaceous is closely related to the better known development of Madras and Madagascar ; it seems likely that the Cretaceous beds of Ramri, Mai-i and Kalaw (Chapter XX) also belong to the same province.

The Tertiaries of Assam are very well developed ; the maximum thickness of the various stages amounts to over 50,000 feet, but it is unlikely that such a great thickness was deposited in any one area. A convenient summary of the Tertiary geology of Assam was given by Mr. Lepper in a paper read before the geological section of the World Petroleum Congress (London, 1933).[1] In this he states, " On present evidence the broad correlation with the Burma succession may be given tentatively :

| Assam-Arakan. | Burma. |
|---|---|
| Dihing Series. | Irrawaddy Series. |
| *Unconformity.* | *Unconformity.* |
| Tipam Series.<br>Surma Series. | Upper Pegu. |
| *Unconformity.* | *Unconformity.* |
| Barails. | Lower Pegu.<br>Upper Eocene. |
| Jaintia Series. | Middle Eocene. |

with the Disang Series probably equivalent to part of the thick Laungsha Shales of Burma."

The lowest Eocene rocks present two distinct facies, known as the Jaintia Series and the Disang Series. The former occurs along a line extending from the south-western part of the Garo Hills to the north-eastern part of the Mikir Hills. The maximum thickness is about 3000 feet and the beds consist of foraminiferal limestones and alternations of shales and sandstones with occasional thin coals ; the fauna shows that the beds are of Lower Kirthar age (Lutetian). It is surprising that these Eocene limestones—so well developed in the central part of Assam—have not been found in the area south-east of the Haflong-Disang fault (a large structural feature running along the south of the Shillong Plateau and thence north-eastwards into the Naga Hills), the more so as thin nummulitic limestones are found in Lower Burma. Their place in the succession is occupied by the very thick Disang Series, which makes up a large part of the Naga

[1] For a fuller account see *Trans. Mining and Geol. Inst. of India*, vol. xxvii, 1932, p. 155.

Hills and Manipur; the predominating rock is a dark shale, but thin well-bedded sandstones are common. The series appears to be many thousands of feet thick; but the base is not certainly known and the sharp folding has prevented accurate determination of details of the succession. Towards the interior of the Naga Hills, the series becomes increasingly metamorphosed, the shales passing into slates and being traversed by numerous veins of quartz. Serpentines also occur, apparently representing intrusive rocks. The correlation of the Disang Series has been much discussed; comparisons have been made with the Negrais beds and with the Axials. The difficulty is due partly to the varying degree of metamorphism shown by the Disangs and partly, it may be, to the inclusion in the Disang Series of rocks much older than those of Mallet's type section. The only definite evidence for the age of the Disang Series is the occurrence of a fauna of Ludian aspect in a series which conformably overlies the Disang shales. As this fauna is separated from the Disangs by some 13,000 feet of deposits, it is likely that the Disang Series is mainly Lower Eocene, and would thus be roughly equivalent to the Laungshe Shales of Burma.

Overlying the Jaintia Series in the central part of Assam and the Disang Series in the eastern part of the province, is a great thickness (up to 15,000 feet) of well-bedded sandstones and shales termed the Barail Series, of Eocene-Oligocene age. Sandstones predominate, except in the middle of the series, and as the beds are traced north-eastwards there is found a considerable development of carbonaceous material, which in Upper Assam includes thick seams of good coal. The Barail Series as a whole is probably roughly equivalent to the range Pondaung Sandstones—Yaw Shales—Shwezetaw Sandstones. After the deposition of the Barail Series, there was an important earth-movement which, over a large part of Assam, brought the Barails out of the shallow waters in which they had been deposited. The resulting land was eroded, and, especially in the Mikir Hills, thousands of feet of Barail beds were removed. Elsewhere the break was less prolonged and submergence in the south-east led to the deposition of the Surma beds—a series of shales, sandy shales, sandstones and conglomerates. The abundant evidence of local unconformities bears witness to the instability of the area, and the overlap by the younger members of the Surma Series indicates a gradual reduction of the land area. In the North Cachar and Mikir Hills there is clear evidence of the old valleys in the Barail land surface having been filled up by Surma beds; very well developed basal conglomerates are common in this part of Assam. Although the Surma Series was first examined in the Surma Valley (in southern Assam) where it is over 10,000 feet thick, it has since been identified in the extreme north-east of the province—although there

very thin—and has been traced into the Arakan coastal strip, where it appears to be very well developed. Fossils are usually very rare, but in a few localities good fossil beds have been discovered, the best known being in and near the Garo Hills, but a very large proportion of the species are new. The palaeontological evidence is sufficient to prove the existence of Aquitanian and Burdigalian beds, and consequently to fix a limit for the age of the unconformity. The principal uplift cannot be dated at all exactly; below the unconformity, the only known Barail fossils (probably Ludian) are several thousand feet down in the series and the Aquitanian Surma fossils are over 6000 feet up in the series. It is reasonable to place the uplift and unconformity somewhere in the Oligocene, but the Assam evidence does not warrant a more definite statement.

It is natural to turn to the more fossiliferous Burma succession for more definite evidence of the age of this important break in the Tertiary sequence, and Mr. Lepper's paper referred to above shows that a well-defined palaeontological break occurs near the middle of the Pegus. Unfortunately a difficulty arises owing to the divergent opinions contained in accounts of the stratigraphy of the upper part of the Pegus; the various classifications proposed are indicated in Chapter XXIII, pp. 233, 246. Mr. Lepper divides the Pegus into six stages and strongly emphasizes that, although each individual stage becomes more arenaceous northwards, the characteristic faunas persist despite the changes of facies. The classification, which has been found to hold good over a very wide area, is given on p. 246.

The unconformity is marked by the great variations in thickness of the Okhmintaung Sandstones and by a palaeontological break below the Pyawbwe Clay. This break occurs at or near the Oligocene-Miocene boundary, but the presence in the Okhmintaung Sandstones of discordances in strike and numerous conglomerates suggests that the earth-movements corresponding to the big Assam uplift occurred well before the end of the Oligocene. Much remains to be learned of the details of this late Oligocene movement, but there is abundant evidence that it was not of merely local importance.

The Surma Series of Assam is followed by the Tipam Series—false-bedded ferruginous sandstones, sandy shales, mottled clays—having a maximum thickness of about 12,000 feet. These beds usually appear to be quite conformable to the Surma beds, but rarely there is evidence of pre-Tipam erosion of the Surmas. The Tipams overlap the Surma Series in a few localities in north-eastern Assam, resting directly on the Barails. Similar and apparently equivalent beds have been described by Dr. Chhibber in the extreme north of Burma—the Namtung Series [1] of the Jade Mines area and the Noija

[1] *Rec. Geol. Surv. Ind.*, vol. lxvi., 1932, p. 88.

Series[1] of the Hukawng Valley. No fossils, other than a very few new species, have been found in the Assam Tipams, but on general grounds it has seemed probable that the series is Middle Miocene. The Tipam Series extends south-westwards into Bengal and the Arakan coastal strip ; there fossils are more abundant and have been thought to confirm this conclusion, but recent evidence is suggestive that they may be somewhat younger and of an Irrawaddian age. The view that the Tipams are approximately Middle Miocene would fit in well with the supposition that they represent the uppermost Pegus of Burma, but at present any correlation is necessarily tentative. Above the Tipam Series is a considerable thickness of pebble beds known as the Dihing Series ; there is probably an unconformity separating the two series, which, on the tentative correlation given above, would represent the unconformity between the Pegus and the Irrawaddian. The Dihing Series is probably the Assam representative of the Siwalik pebble beds.

The sub-Recent and Recent deposits of Assam are comparable with those of Burma (Chapter XXXII, p. 270) ; high-level river terrace pebble beds occur in several localities and the alluvium of the present valleys is of very great but unknown thickness.

The Tertiary deposits of Assam, like those of Burma, are remarkable for the number of occurrences of petroleum. Oil and gas are associated with beds of the Barail, Surma and Tipam Series in Assam, a range very similar to that in Burma, where they are known from Middle Eocene to Middle Miocene. Mud volcanoes (Chapter VI) are not known in Assam, but this is probably merely on account of the heavy rainfall ; had the climate been dry, the " pungs " of Namchik, Jaipur, etc., would doubtless have been mud volcanoes similar to those of Burma.

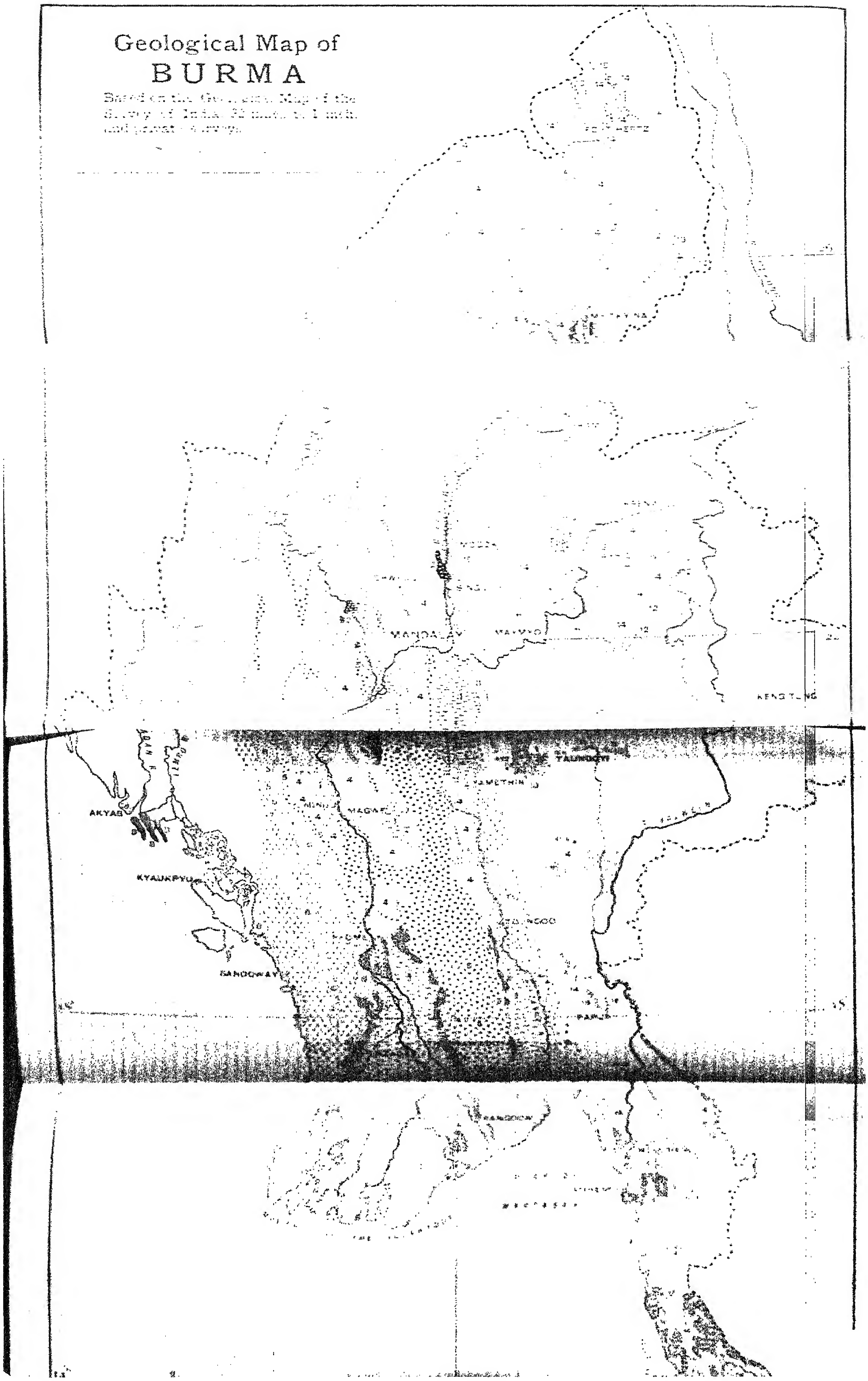
Thus, in the post-Jurassic beds, the resemblances between Assam and Burma include the nature of the deposits, the range of petroleum occurrences, and the presence of two important Tertiary unconformities. The most striking difference is the abundance of fossils in Burma and their paucity in Assam.

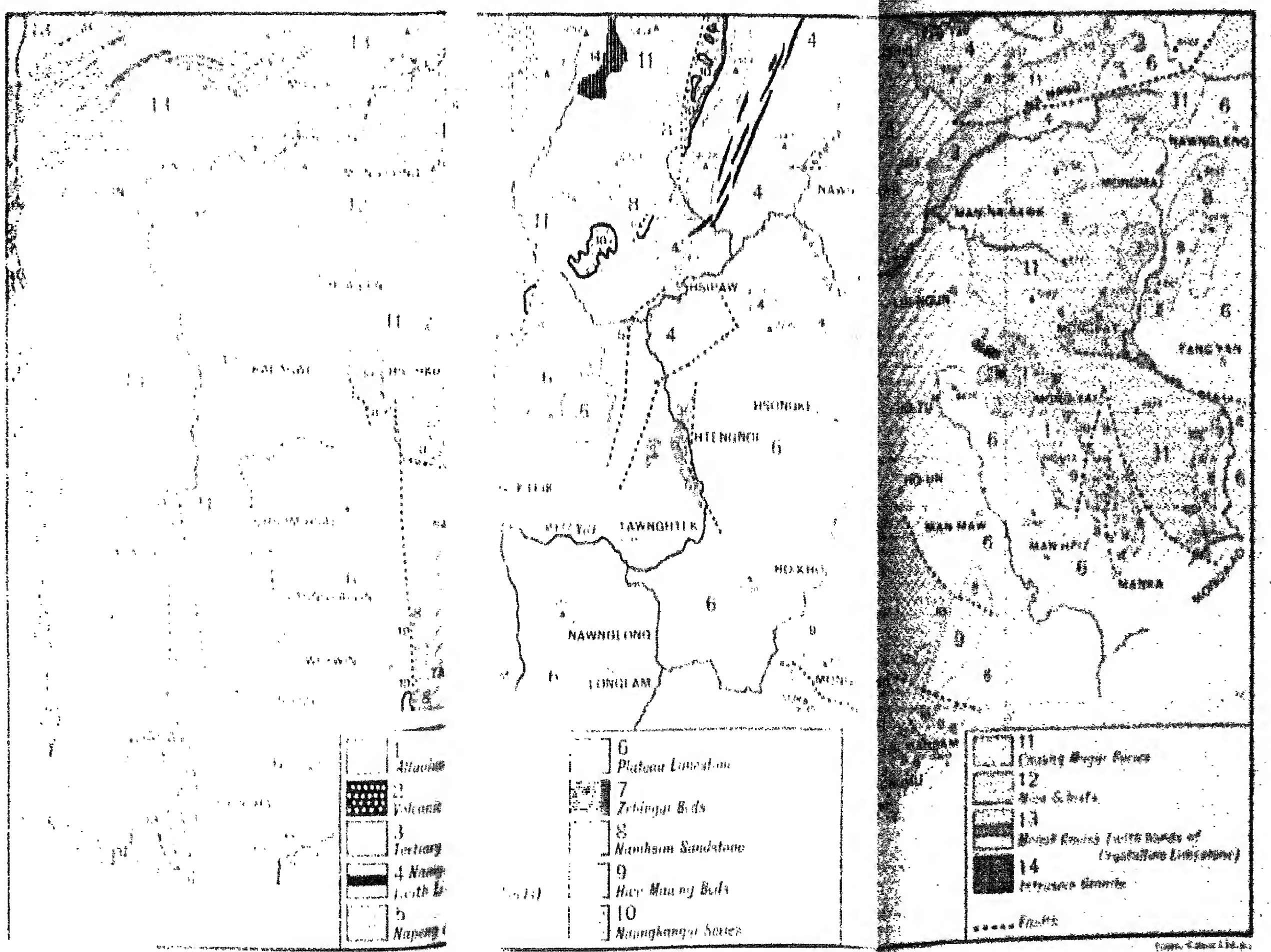
Structurally, the Assam-Arakan region offers many points of resemblance to the Irrawaddy-Chindwin region of Burma. The hill-ranges separating the two regions consist of highly folded and faulted Tertiary and pre-Tertiary beds, flanked on each side by a broad geosynclinal area of Tertiary beds, these being in turn flanked by the Shillong Plateau west of the Assam-Arakan Tertiary belt and by the Shan Plateau east of the Burma Tertiary belt. The folding of the newer rocks of Burma closely follows the trend of the main belt of the Tertiaries ; in Assam, the Tertiary outcrop broadens south-westwards and the margins of the area are not so nearly parallel as the two

[1] *Rec. Geol. Surv. Ind.*, vol. lxv, 1931.

margins of the Burma Tertiary belt, but the general strike accords roughly with the boundaries of the Tertiary outcrop. In the Surma Valley the anticlinal folding is somewhat similar to that common in the Irrawaddy-Chindwin area but there is a greater tendency to the development of overthrust strike-faults. Farther north-east, there has been very great compression between the Himalayan and Naga Hills uplifts and most of the Tertiary outcrop is a succession of overthrust strips separated by faults with a throw of many thousands of feet. Considered on a broad scale, it is evident that in both provinces the movements responsible for the present configuration and structure occurred very late in Tertiary time and were of enormous magnitude, yet despite their late age there has been, since their initiation, such active denudation that along the lines of greatest elevation many thousands of feet of beds have been removed.

The later igneous activity of Burma finds no parallel in Assam; the igneous rocks of the Abor and Jaintia Hills are pre-Tertiary and the only later intrusions are those represented by the serpentines discussed in Chapter XXVIII.


Geological Map of
BURMA
MANDALAY
TAUNGGYI
YAMETHIN
AKYAB
KYAUKPYU
SANDOWAY
KENG TUNG




Geological ...n of the NORTHERN SHAN STATES

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